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The WELDING JOURNAL

Official Publication of the American Welding Society

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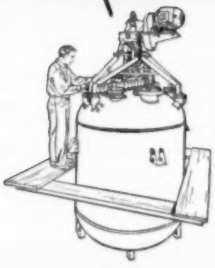

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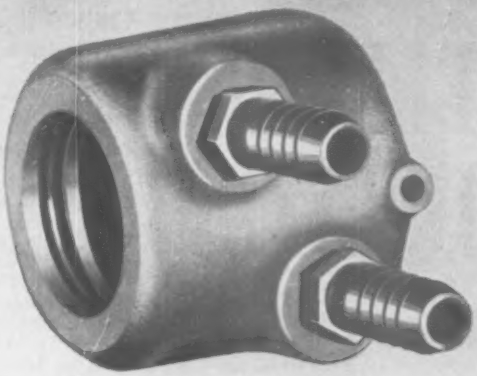

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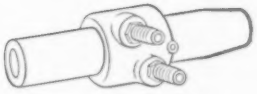

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cover: Front view of an assembled trolley on an open hearth charging machine. *Courtesy The Wellman Engineering Co.*

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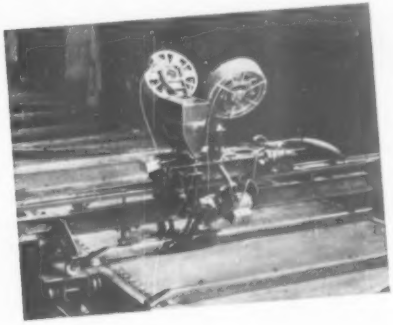
Ideas on Welded Design—For the Engineer's Notebook

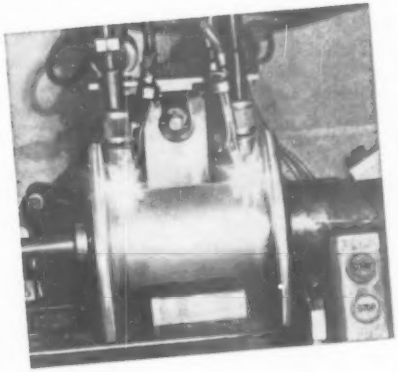
MAKE WELDS SIMULTANEOUSLY

When both ends or both sides of an object must be welded, both welds can often be made simultaneously. Production can thus be doubled — welding time cut in half!

Two UNIONMELT welding heads or two HELIARC torches can often be used — with the weldment turning or moving under stationary welding equipment, or with the welding units moving over the workpiece. Here are examples:



Two UNIONMELT welding heads are simultaneously welding both sides of a stake, joining it to the side panel of a railroad car. The bridge that supports the carriage can be easily shifted for welding both the stakes and diagonal side braces.



Fabrication of aluminum spools is speeded by use of two stationary HELIARC welding torches. The formed ends are joined to the barrel by girth butt welds. The pieces are held together over a backing mandrel, and turned under the HELIARC torches which make both welds simultaneously.

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The WELDING JOURNAL

volume 29 October 1950 number 10

Rehabilitation of Ore Cars

Repair of 7000 ore cars in winter becomes a major production maintenance problem. The rebuilding of 400 of the older cars by welded construction is described

by J. F. Likarish

YOU are probably all familiar with the fact that most of the iron ore fed into the steel industry comes from the giant open-pit mines north of Lake Superior. As a preface to the important part that welding now holds in the movement of ore, I would like to give you a few facts on its mining and transportation.

J. F. Likarish is General Car Foreman, Great Northern Railway, St. Paul, Minn.

Scheduled for presentation at Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

Most of the ore of the Mesabi Range is dug from open pits, the largest of which is the famous Hull-Rust-Mahoning Mine Pit near Hibbing, Minn. (Fig. 1). This great pit is roughly 3 miles long, 1/2 to 1 mile wide, and measures a maximum 435 ft. in depth. It also has 55 miles of railroad tracks. Shovels of 14-ton capacity load the ore into railroad cars. Most of these cars are then moved to the Great Northern Kelly Lake Yard where they are made up into trains of 180 cars and hauled to the classification yards at Allouez, just south

Figure 1

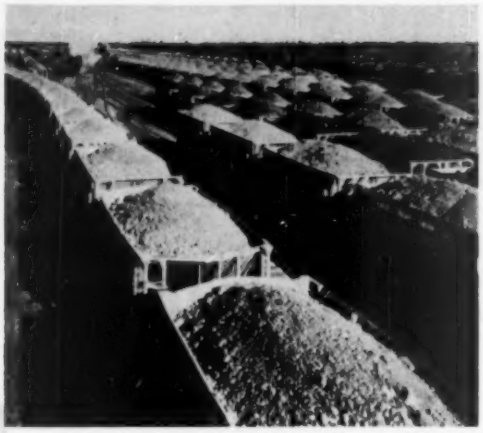


Figure 2

of Duluth (Fig. 2). The capacity of the classification yard at Allouez is over nine thousand cars.

Since ores from the various mines differ slightly in chemical composition, the cars are sorted and then delivered to the docks for further blending in separate pockets of each dock (Fig. 3). The Great Northern Railway has four ore docks at Superior, Wis., the shortest of which extends over one-third of a mile into the harbor. These docks are steel and concrete structures 80 ft. above water. Capacity of the four docks is 441,800 gross tons of ore. Under the dock tracks there are 1350 ore pockets each holding five carloads; from these pockets chutes are lowered to pour the iron ore into the holds of the ships waiting below.

The Great Northern has 7200 drop-bottom hopper cars assigned to iron ore service. These cars are 75-ton capacity, all steel, 1200 cu. ft., 24 ft. long; equipped with A. B. brakes and steel wheels.

Ore trains consist of 180 cars or 16,200 tons gross weight per train. The distance from the mines to the docks at Superior is 105 miles. The Great Northern moves an average of nine of these trains per day and hauls approximately 23 million tons of ore per season. During a seven- or eight-month season just as many

Figure 3

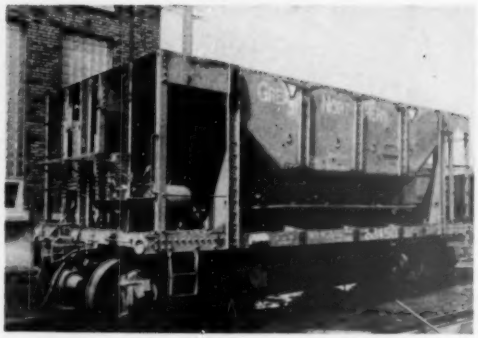


Figure 4

cars as possible have to be in serviceable condition.

All repair work and reconditioning must be done in the winter. Just before the close of the ore season, a very thorough inspection is made of all ore cars and they are classified as to the type of repair required. Light repair work is done at our Allouez repair yard, and the heavy repair and rebuilding at our Superior steel shops. Our cars were originally purchased from a car builder and for the most part are of riveted construction.

Last year it was decided that four hundred of the older cars built in 1920–24 were to be reconditioned, and instead of the riveted type construction, an all-welded type construction would be used for new baskets or hoppers. The reason for this change was that a saving could be made in labor and material. For instance, by making new baskets by welding, four hundred $^{3}/_{8}$-in. rivets per car would be eliminated. The baskets would be more efficient, too. Welded construction of the basket would eliminate ore sticking to rivet heads, and cars would empty more easily and completely.

The old baskets were stripped from the underframes, then the underframes and trucks were repaired outside the shop. All of the new basket prefabrication and assembly work was done inside the shop, which measures 108 x 240 ft. Crane facilities in the shop are not un-

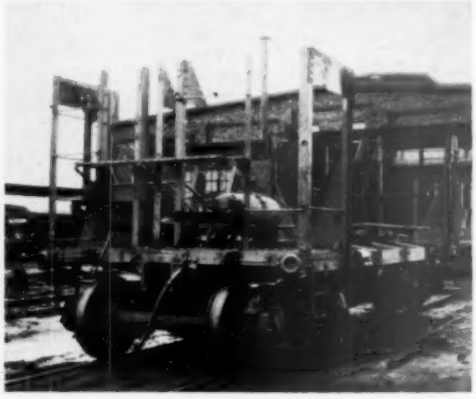


Figure 5

Figure 6

usual, and other equipment consists of a press brake, used to form end side slope sheets, a gang punch shears, stationary and portable flame-cutting machines, three automatic submerged melt welding heads, three flexible welders of the submerged type, and ten electric welding machines. More of the latter are brought in as needed.

Each car received a complete new welded hopper or what we call a basket. Trucks and underframes were in good condition and in practically all cases it was cheaper to repair them than to buy new equipment. By utilizing various jigs and devices, and assembly-line methods, eight cars per eight-hour day were reconditioned and ready for service. Most of the illustrations for this paper show the repairs on an order of 70 ore cars. This repair work varied slightly from the repairs made to 330 cars done earlier.

Figure 4 shows a car ready for removal of the old riveted basket. All rivets were removed by flame-cutting. Side and end top angles have been removed. These will be straightened and welded to any car of this type which is going through the reconditioning. Note the holes which are flame-cut near the top of the basket. An overhead crane with a four-hook sling lifts out the basket. Steam hole or poke hole covers are removed and re-used on new baskets.

Figure 5 shows three repaired underframes headed into the shop door. Just inside the shop the new basket will be lowered into place to start the re-assembly. Notice that the couplers and draft gears have been removed. After close inspection they will be repaired or replaced by new units if found to be defective.

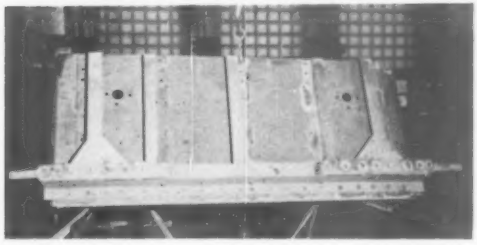


Figure 7

Figure 8

The next steps described will be in the fabrication of subassemblies for the new all-welded baskets. Figure 6 shows an automatic flame-cutting machine used in this program. In the picture, eleven sheets of $^1/_4$- x 104- x 120-in. copper-bearing mild steel are being cut. The machine cuts the pile of sheets at the rate of $7^1/_2$ in. per minute. A No. 8 cutting nozzle is used. Oxygen pressure is 42 psi.; acetylene, 3 psi. Note that the operator uses a crowbar to force sheets together as the cut progresses. Strong backs used to clamp the plates have built in slots into which the crowbar fits easily. One operator using this machine cuts eight sets of car end and side sheets in eight hours.

Figure 7 shows a reconditioned hopper bottom door. A "Z" bar support from an old door is welded to the new door plate that is cut to size and press-formed. Old "Z" bars were straightened in a shop-made press at a

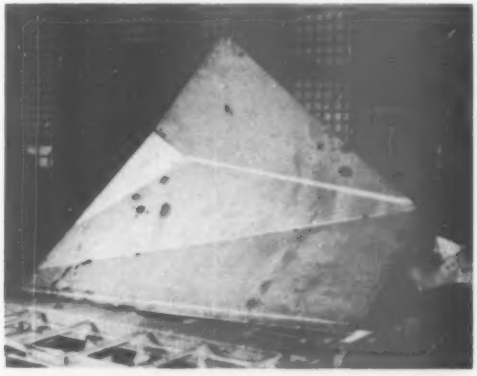


Figure 9

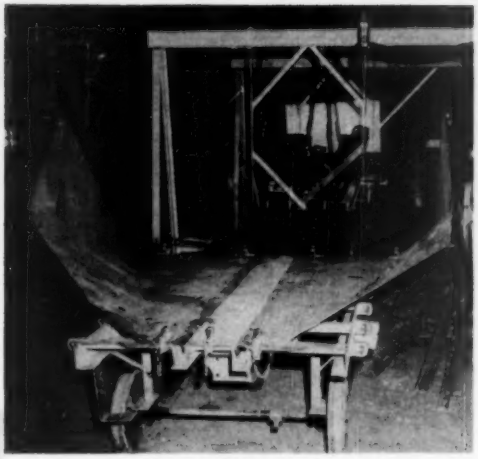


Figure 10

special station equipped for that work. In the 330-car order, the construction of the door made it possible to use semiautomatic submerged melt plug welds between the reinforcements and the door sheets. There were 41 plug welds per door. In door repairs as shown here, intermittent hand-arc fillet welds were used in the construction with some plug welding.

Figure 8 shows the station where new side stakes were welded to side slope sheets by manual arc welding. A 500-amp. machine with $^{5}/_{16}$-in. coated rod was used for this operation.

Assembling parts of end slope sheets is shown in Fig. 9. A small formed channel at center of jig will be welded to two large sheets, one of which is being positioned. On the nearest end of the cart, notice the top angle which is also a part of this assembly. Also note

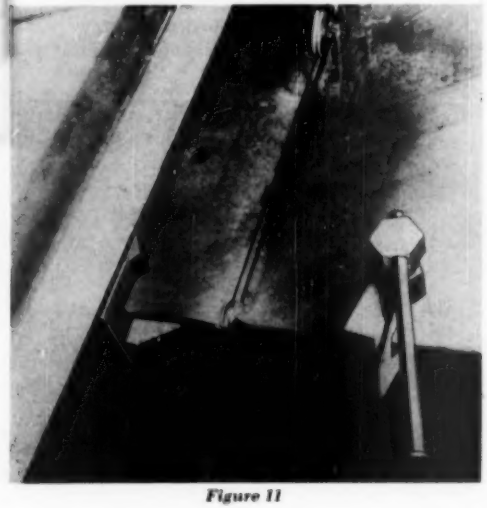
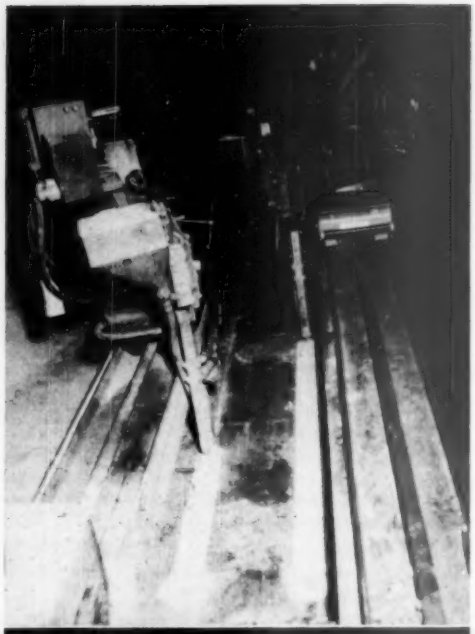


Figure 11



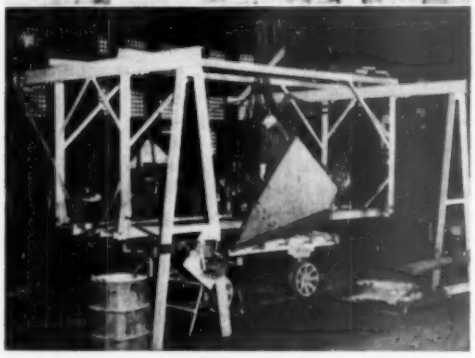


Figure 12 (Top)
Figure 12 (A) (Bottom)

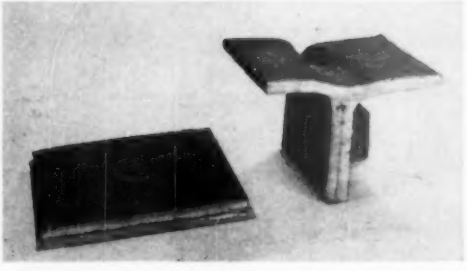


Figure 13

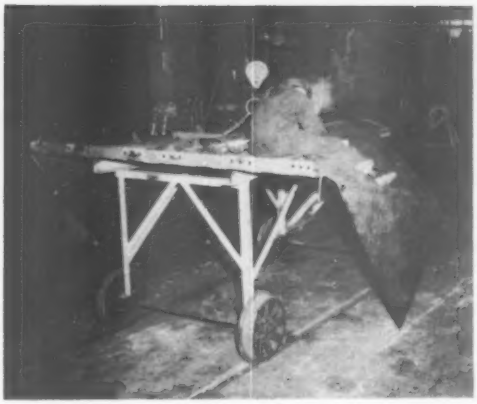


Figure 14

the hinged C-clamps used to hold parts on this rolling jig. Finally, note the six telescope bars, which can be wedged to hold the sheets together during welding.

Figure 10 illustrates how the end slope sheet is assembled, ready to roll under the submerged welding heads in the background. We used four of these portable jigs.

Figure 11 is a close-up of the flange joint to be welded between the end and channel or middle section of the slope sheet. A soft $^1/_4$-in. rod is tack welded at one end into the base of the root flange-weld that is made by submerged melt welding. The small concave wheel rides on the rod, guides the machine and, at the same time, holds the rod down in the groove. The purpose of this soft steel rod is to increase the rod deposit per minute.

Shown in Figure 12 are two U-type welding heads simultaneously making root flange welds in the end slope sheets. Each weld is 9 ft. long and made at 14 in. per minute; a.-c. voltage is used. The current is 650 amp., and the rod is $^3/_{16}$ in., Type No. 36. The melt is designated as No. 80, 20 x 200 mesh. Figure 12 (*a*) shows how the jig cart positions the part under the

Figure 15

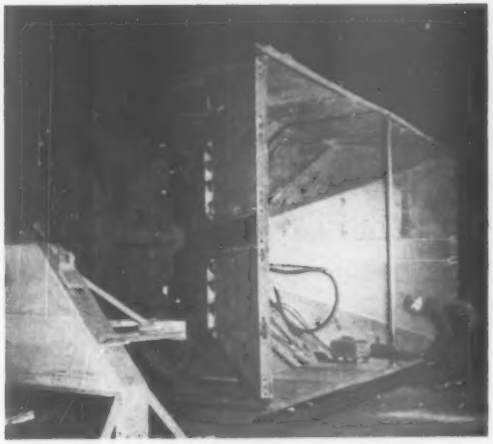


Figure 16

Figure 17

Figure 18

welding head and also how the head and track are suspended.

Figure 13 shows specimens of the submerged melt welding used in this work. At the left is a plug weld, while on the right you see the cross section of the root-flange weld made in the end slope sheets.

Figure 14 shows the nearly completed end slope sheet to which one of two stiffener angles is being arc welded. Note the top end angle in place. This particular type of end angle construction made it necessary to fillet

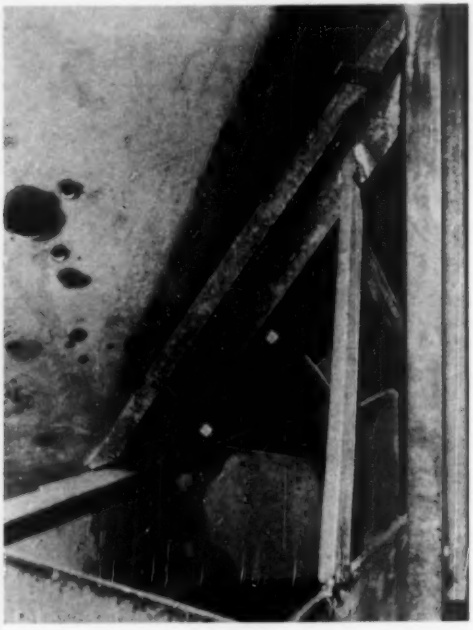


Figure 19

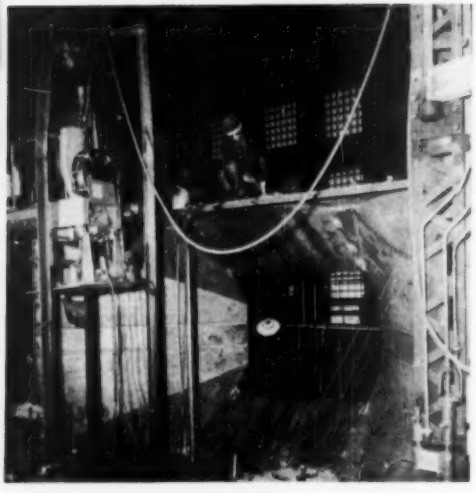


Figure 20

Figure 21

weld the angle to the sheet by the hand-arc method. The construction of the cars in the 330-car order made it possible to use automatic welding of the end top angle without removal of the assembly from this jig. This was done by swinging a track and welding head over the assembly in this welding line.

Up to this point I have described the steps taken in dismantling the cars and the assembly of the subassemblies that become part of the new baskets or hoppers. From here on the final assembly operations will be shown and described.

A carman is positioning one of the side slope sheets in the basket jig, as shown in Fig. 15. Four of these jigs were used in this program. While two are used for positioning, the other two are used at the welding stations. Note the side stake on the near edge of the side slope. The end slope sheet will be placed in the jig at the end nearest the camera. The side stake will overlap the butt joint of the side slope sheets.

Figure 16 shows a general view of the jig holding an almost complete basket. Note that the dollies are removed from each end of the jig so that the jig can be turned 360° and held in four different welding positions. In this view the intermittent edge welding can be seen on the stiffeners on the end slope sheets. The flexible semiautomatic welding head can be seen inside the basket.

Figure 22

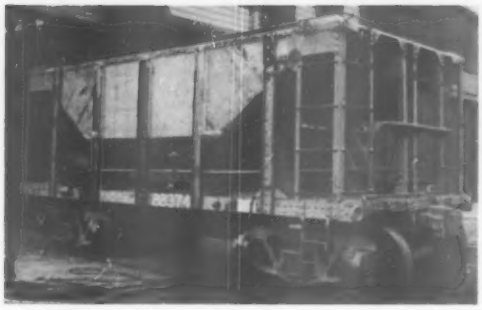


Figure 23

The flexible welder in Fig. 17 is making intermittent welds between top angle and side and end slope sheets. Current is 350 amp., 30 volts, while rod is $^{5}/_{32}$ in. Speed is 12 to 14 in. per minute, with full penetration.

In Fig. 18 the flexible welder is shown making the butt weld between end and side slope sheets. This welding method was also used to make two plug welds at the top of the side sheets, the weld going through to the side stakes, making a total of eight plug welds per car.

The copper back-up bar on the outside of the basket is seen in Fig. 19. This bar is at the butt joint between end and side slope sheets below the side stakes.

Figure 20 requires some clarification. In the 330-car order previously mentioned it was possible to use the old car side stakes on new baskets. In preparation for their re-use, rivets were removed by flame-cutting and through the rivet holes plug welds were made to the sheets at the welding station shown here. This merely illustrates the elevator device used to bring the rod and melt feed machine to the level to make this plug weld possible. At this station also, the butt-welding inside the basket was done with the welding machine at the lower position. In other words, the welder was used at the upper position for plug welds and at the lower for butt welding. There were 106 plug welds per car on the 330-car order just mentioned. As shown in a previous photo, side stakes were manually arc welded in the 70-car order, pictures of which are shown in this paper. Figure 21 shows the almost completed basket being

Figure 24

lifted from one of the jigs. It will be moved by crane down the shop and placed in a reconditioned underframe.

Figure 22 is a view of the inside finished basket. The few rivets used in these rebuilt cars were on the corner angles, safety appliances and doors. Rivets are not desirable in the doors. However, they were used because the hinges were malleable iron and in too good a condition to scrap.

The exterior of the basket and car just shown is seen in Fig. 23. The car is being pulled from the shop by winch and a few feet farther to the left it will be painted and stenciled. Following the assembly of basket to underframe the air line pipes were renewed, hand brakes were reconditioned and tested, and the door closing mechanisms were installed and tested.

Figure 24 is a completed rehabilitated car. You will immediately notice the construction differences between this and the one first shown. The car here is one of the 330-car order in which the side stakes were re-used by plug welds to the new side sheets. In this type of car the top angle is on the inside of the slope sheets.

May I very briefly conclude this paper by stating that welded construction of new baskets has given us a car that will provide service equal to that of a new car. The complete cost of this rehabilitation has resulted in a substantial saving to the Great Northern Railway.

A Practical Method for Obtaining Consistent Resistance Welds

A plan for applying a recommended spotwelding schedule in production through a simple correlation of the characteristics of a specific spot-welding machine with the schedule

by J. W. Kehoe

ABSTRACT

A plan has been developed to apply a recommended spot-welding schedule in all thirty Westinghouse production divisions using the resistance-welding process and covering over 500 machines. This is facilitated with the aid of a current meter connected to a current transformer installed in the primary side of a resistance-welding machine. This schedule can be applied to any spot-welding machine after its characteristics are determined. The key to the plan is a chart which correlates the schedule to the machine. The plan is simple and requires but a few hours to work out.

The characteristics of any particular machine are obtained as follows:

1. Measure the welding current with an ammeter.
2. Measure the welding force with a force gage.
3. Measure the welding time with a time meter or cycle counter.
4. Develop a chart incorporating the above information with the recommended schedules.

Coupled with the chart is the use of standardized electrodes or tips, made possible with recommended overlap and edge distances as shown in the schedule, an economic shop-testing method for determining the weld nugget diameter, and a pneumatic tip dresser requiring 15 seconds' time to restore the tip contour after normal wear. The electrode combination of one spherical radius face and one flat face has much longer life than any other standard combination, such as truncated cone or flat electrodes. This has been substantiated by proven tests. With the meter connected as outlined, the effect of throat opening and depth, steel in the throat, reduced voltage and control deficiencies, is instantly reflected in the meter's change from a predetermined setting.

Proof of consistent quality welds after a trial on various types of resistance-welding machines, including spot, seam and projection welding, has convinced management of the merits of this plan; and their support, both engineering and manufacturing, has been forthcoming. The ease of welding and the absence of "spitting" and expulsion of metal have more than won over the operator—the forgotten man in the entire cycle. In over 150 separate installations of this plan in the past year, over 300 welding operators have favored it without exception. In the manufacturing sections it has been the operator's favorable reaction which has expedited acceptance of this practical method for obtaining consistent resistance welds.

Considerable assistance has been obtained in the past from the *Recommended Practices for Resistance Welding*, which in 1942 was the first publication toward standardization of resistance-welding information. Additional information was published in the 1946 edition of the same.

INTRODUCTION

MANY worth-while ideas and suggestions have been made toward promoting the advancement of resistance welding in regard to the widely used methods of spot, seam and projection welding. Some very good schedules and recommendations have been compiled and advocated for general use. One of the drawbacks to putting this information into wide usage has been the lack of suitable, inexpensive metering equipment so that recommended welding current values can be checked by the welding operator. Considerable progress has been made and suitable instruments for pressure and time measurements have been available for several years, but an inexpensive, practical form of measuring current had not been readily available until the past year. A method has been developed for Corporation-wide application in the Westinghouse Electric Corp. whereby, with a given resistance-welding schedule, the availability of an easily-read current meter and other pertinent information—such as electrode sizes, recommended pressure settings, weld time settings, spot spacings, edge and overlap distances, etc.—have been made available to operating personnel, supervision and engineering. This was accomplished by the wholehearted cooperation of the various departments involved, through the efforts of a Resistance Welding Process Committee which was appointed as a subcommittee of the Metals Joining Committee of the Corporation.

J. W. Kehoe, Section Engineer, Metals Joining Laboratory, Headquarters Mfg. Engineering Dept., Westinghouse Electric Corp., East Pittsburgh, Pa.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

RESISTANCE SPOTWELDING SCHEDULES FOR "MILD STEEL" (.18 CARBON MAX)

WELDING DATA							INSPECTION & ENGINEERING DATA						
THK COMB. NOTE 1 (IN.)	ELECTRODE DIA & SHAPE COMB. SEE BELOW	WELDING FORCE LB NOTE 2	WELD TIME CYCLES	WELDING CUR AMP NOTE 3	SHORT CKT CUR THRU COPPER NOTE 4	HOLD TIME CYCLES NOTE 5	DIA OF WELD NUGGET OF MULTI-WELDS INCHES NOTE 6	MIN. SPACING IN.	MIN. MULTI-WELD SHEAR STR LB BASED ON STL OF ULT STR OF 45,000 P.S.I.	SINGLE WELD SHEAR STR LB NOTE 7	MIN. EDGE DISTANCE IN.	MIN. OVER-LAP DIS-TANCE	THK COMB. NOTE 1 (IN.)
.015-.015	1 or 2	250	3	7000	8200	10	3/32	1/4	150	150	1/8	1/4	.015-.015
-.036	1 or 2	250	9	7000	8200	10	5/32	1/4	150	200	5/32	5/16	.036
.050	1 or 2	250	9	7000	8200	10	5/32	1/4	150	200	5/32	5/16	.050
.064	1 or 2	250	9	7000	8200	10	5/32	1/4	200	200	5/32	5/16	.064
.036-.036	1 or 2	250	9	7000	8200	10	3/32	1/4	350	500	5/32	5/16	.036-.036
.050	1 or 2	400	14	8400	9900	20	13/64	3/8	550	700	5/32	1/2	.050
.064	1 or 2	400	14	8400	9900	20	13/64	3/8	550	700	1/4	1/2	.064
.078	1 or 2	600	21	9200	10800	20	3/16	1/2	700	1000	1/4	1/2	.078
.094	1 or 2	600	21	9200	10800	20	3/16	1/2	700	1050	1/4	1/2	.094
.109	2	800	28	11400	13400	30	9/32	5/8	900	1250	5/16	5/8	.109
.125	2	800	28	11400	13400	30	1/4	5/8	900	1300	5/16	5/8	.125
.050-.050	1 or 2	400	14	8400	9900	20	3/16	3/8	725	1000	1/4	1/2	.050-.050
.064	1 or 2	600	21	9200	10800	20	1/4	1/2	1000	1500	1/4	1/2	.064
.078	1 or 2	600	21	9200	10800	20	1/4	1/2	1000	1500	1/4	1/2	.078
.094	2	800	28	11400	13400	30	1/4	5/8	1100	1700	5/16	5/8	.094
.109	2	800	28	11400	13400	30	17/64	5/8	1100	1700	5/16	5/8	.109
.125	2 or 3	1050	37	11400	13400	30	17/64	7/8	1700	2200	3/8	3/4	.125
.156	2 or 3	1300	47	14600	17200	30	5/16	7/8	1800	2400	3/8	3/4	.156
.064-.064	1 or 2	600	21	9200	10800	20	9/32	1/2	1100	1800	1/4	1/2	.064-.064
.078	2	800	28	11400	13400	30	1/4	5/8	1600	2200	5/16	5/8	.078
.094	2	800	28	11400	13400	30	15/64	5/8	1700	2200	5/16	5/8	.094
.109	2 or 3	1050	37	11400	13400	30	9/32	7/8	2100	2700	3/8	3/4	.109
.125	2 or 3	1050	37	11400	13400	30	1/4	7/8	2100	2700	3/8	3/4	.125
.156	2 or 3	1500	59	14600	17200	30	5/16	1	2400	3100	7/16	7/8	.156
.188	2 or 3	1500	59	14600	17200	30	1/4	1	2400	3300	7/16	7/8	.188
.250	3	2200	93	19200	22600	45	9/32	1	2900	4100	1/2	1	.250
.078-.078	2	800	28	11400	13400	30	9/32	5/8	1900	3400	5/16	5/8	.078-.078
.094	2 or 3	1050	37	11400	13400	30	17/64	7/8	2800	3700	3/8	3/4	.094
.109	2 or 3	1050	37	11400	13400	30	9/32	7/8	2900	3900	3/8	3/4	.109
.125	2 or 3	1300	47	14600	17200	30	11/32	7/8	2900	3900	3/8	3/4	.125
.156	2 or 3	1500	59	14600	17200	30	5/16	1	2900	3900	7/16	7/8	.156
.188	2 or 3	1500	59	14600	17200	30	11/32	1	3000	3900	7/16	7/8	.188
.250	3	2200	93	19200	22600	45	11/32	1	3000	4500	1/2	1	.250
.094-.094	2 or 3	1050	37	11400	13400	30	9/32	7/8	2700	3600	3/8	3/4	.094-.094
.109	2 or 3	1300	47	14600	17200	30	5/16	7/8	3000	4800	3/8	3/4	.109
.125	2 or 3	1300	47	14600	17200	30	5/16	1	3900	5000	3/8	3/4	.125
.156	2 or 3	1500	59	14600	17200	30	11/32	1	4300	5500	7/16	7/8	.156
.188	3	2200	93	19200	22600	45	3/8	1	4400	6500	1/2	1	.188
.250	3 or 4	2700	130	22200	26100	45	3/8	1-1/8	5000	7900	5/8	1-1/4	.250
.109-.109	2 or 3	1300	47	14600	17200	30	5/16	7/8	2900	4000	3/8	3/4	.109-.109
.125	2 or 3	1500	59	14600	17200	30	3/8	1	3500	5900	7/16	7/8	.125
.156	2 or 3	2200	93	19200	22600	30	7/16	1	4600	6600	7/16	7/8	.156
.188	3	2200	93	19200	22600	45	7/16	1	4600	7400	1/2	1	.188
.250	3 or 4	2700	130	22200	26100	45	15/32	1-1/8	5100	8200	5/8	1-1/4	.250
.125-.125	2 or 3	1500	59	14600	17200	30	5/16	1	4000	4800	7/16	7/8	.125-.125
.156	3	2200	93	19200	22600	45	15/32	1	5000	7300	1/2	1	.156
.188	3	2200	93	19200	22600	45	7/16	1	5100	7900	1/2	1	.188
.250	3 or 4	2700	130	22200	26100	45	5/8	1-1/8	6200	9300	5/8	1-1/4	.250
.156-.156	3	2200	93	19200	22600	45	1/2	1	6400	9400	1/2	1	.156-.156
.188	3 or 4	2700	130	22200	26100	45	19/32	1-1/8	7200	10500	5/8	1-1/4	.188
.250	3 or 4	2700	130	22200	26100	45	19/32	1-1/8	7400	11800	5/8	1-1/4	.250
.188-.188	3 or 4	2700	130	22200	26100	45	1/2	1-1/8	8000	13600	5/8	1-1/4	.188-.188
.250	4	3700	230	28000	33000	90	5/8	1-3/8	11700	14000	3/4	1-1/2	.250
.250-.250	4	3700	153	28000	33000	90	3/4	4	15000	15000	3/4	1-1/2	.250 .250
.250-.250	4	3700	230	28000	33000	90	5/8	1-3/8	13500	15000	3/4	1-1/2	.250-.250

COMBINATION 1: .482 D-2 IN. SPHERICAL RADIUS FACE
.482 D-FLAT

COMBINATION 2: 5/8 D-2 IN. SPHERICAL RADIUS FACE
5/8 D-FLAT

COMBINATION 3: 7/8 D-6 IN. SPHERICAL RADIUS FACE
7/8 D-FLAT

COMBINATION 4: 1-1/2 D-6 IN. SPHERICAL RADIUS FACE
1-1/2 D-FLAT

For electrode details, see Works Standards Sheets - 7206 Series.

Figure 1

(See notes, next page)

Explanatory Notes Pertaining to Chart on Spotwelding Schedules

Note 1: On dissimilar thickness combinations, the average thickness determines the weld schedules. These average thicknesses are established to the nearest similar thickness combination. Example, average thickness of 0.050 to 0.094 is 0.072. Average thickness is taken as 0.078. For similar thicknesses not listed, use nearest thickness combination.

Note 2: Welding Force is the net electrode force measured in pounds exerted on the work.

Note 3: Welding Current is the secondary current during the actual welding cycle. It is not the same as Short-Circuit Current. Welding Current variation during welding should be held to ±5%.

Note 4: Short-Circuit Current through copper is used as an aid in setting the welding machine to the schedules. If this value is obtained while firing the machine through copper, it will give approximately the correct welding current. Final adjustments should be made on the work.

Note 5: Hold time is the time required to solidify the weld under pressure after the welding current has been terminated. This time is set on the welder control.

Note 6: The diameter of the weld nugget is the basis for determining the weld strength. The weld diameter should not be confused with the imprint of the electrodes on the work.

Note 7: Shear strengths are obtained by pulling the overlapped weld joints to destruction in a standard testing machine with the specimens unconfined. These are generally known as Tension-Shear tests. These particular shear strengths are obtained with widths equal to 4 times the minimum edge distance.

PART I—ADAPTING A SCHEDULE TO A MACHINE

The resistance spotwelding schedules for mild steel, as shown in Fig. 1, comprise part of the general process specification covering this resistance-welding method. This schedule applies to clean, unscaled uncoated steel of maximum 0.18 carbon. Some of the headings of the columns are readily understandable for those who have had reference to the A.W.S. schedules contained in the *Recommended Practices for Resistance Welding*, 1946 edition, and in the *Welding Handbook*, the third edition of which was released in January, 1950.

Let us examine this schedule briefly. You will notice that one half of the schedule is divided into welding data, which is primarily manufacturing welding information, and the other half is inspection and engineering data. The first column covers the various thickness combinations which are welded with the electrode combinations shown in the second column. It has been assumed that there will always be a "no marking" requirement on at least one member of a thickness combination. However, the information contained in this schedule for the various thickness combinations is flexible enough so that the flat electrode can be against either the thin or thicker member of the thickness combination. For example, in the case of welding 0.094-in. thick material to 0.250 in., it makes no difference as far as the strength of the joint is concerned whether the spherical radius tip is used against the thinner or thicker member. In any case, the engineer will design around the shear strengths, shown in Column 10 on the chart, where more than one spot is required. If there is no marking requirement, two spherical radius-faced tips may be used, in which case the weld strengths are increased 10% because of the increased current density. In cases where single spot welds can be used, the single weld shear strengths, shown in Column 11, are approximately 25% higher than the shear strengths of the multiwelds, shown in Column 10. This is brought to the design engineer's attention on an Engineering Design Standards Sheet now in preparation. On this same sheet, it is shown that the ratio between tensile and shear strengths is 30%. Thus, the design engineer is told that $3^1/_3$ spot welds in tension are required for every spot in shear, dependent upon stress distribution which is illustrated in the Engineering Design Standards Sheet being prepared.

Column 3, welding force, represents the net electrode force measured in pounds exerted on the work. This is measured with standard available pressure gages.

Column 4 is the welding time in cycles of the current duration.

Column 5 is the welding current measured in amperes. It is the secondary current required for the actual weld.

Column 6 represents the short-circuit current measured through copper in the exact setup to be used for the production-welding operation involved.

Column 7 is the hold time in cycles, which is generally set on the welding sequence timer. Thus, the information in the first seven columns is all that is necessary for the manufacturing section to make a weld on any given thickness combination as shown in Column 1. The column headings on the balance of the schedule under inspection and engineering data are self-explanatory.

Because of the wide variations in thickness combinations, such as two pieces of 0.015 in. on through to two pieces of $^1/_4$-in. thickness, it has been found advisable and practical to install the current transformer in the primary side of the welding machine, and to this transformer connect a pointer-stop current meter. Measuring on the primary side will eliminate the current transformer saturation effect generally encountered in measuring the high secondary currents involved during the welding cycle.

After the transformer and the pointer-stop meter, shown in Figs. 2 (*a*) and (*b*), have been installed, which generally requires a half hour or less, the following steps are taken toward establishing a chart giving

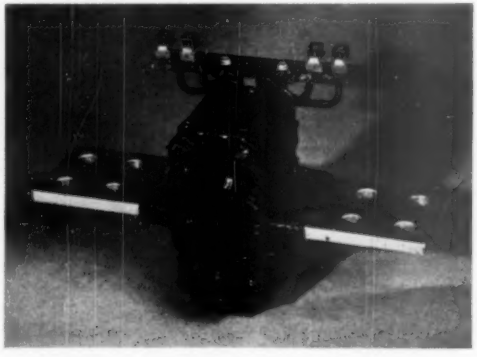


Fig. 2 (a) Current transformer

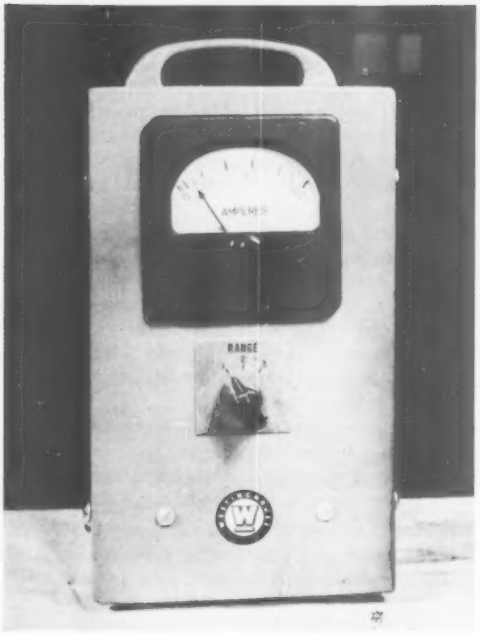


Fig. 2 (b) Current meter (front view)

Fig. 3 Current meter and time box

measured current output on the particular welder on which the current transformer and meter have been attached.

1. Obtain the welder transformer ratio, either by referring to the welder manufacturer's nameplate (sometimes mounted on the machine), or to information generally contained in the instruction book which accompanies the welder when received from R.W.M.A. member companies, or by actual measurements which require a few minutes. The weld transformer ratio can be measured by placing a jumper across the ignitron contactor and closing the welding circuit. The open secondary voltages for each tap setting of the machine are then measured along with the primary voltage on the machine at the time of measurement. The ratio of these voltages will give the voltage ratios of the various taps on the machine. This information will enable one to know what size of current transformer should be used on any specific machine. For example, a machine with a nameplate rating of 30,000 amp., which has a voltage ratio of 30 on the high tap, should indicate that a transformer capable of carrying at least 1000 amp. is required.

2. With the proper calculations of the weld transformer ratio, the correct ratio multiplier for each tap or control setting which is to be used with the current meter reading for each tap or each heat control setting is determined.

3. Take the short-circuit calibration of the welding machine through a piece of copper between the electrodes or a copper bar in the position in which the machine is used most frequently. Note the current meter reading for each adjustment of the tap changer or heat control.

4. Obtain welding force calibration either from the welder manufacturer's information or with a force gage.

5. Check the weld time settings with a time meter or cycle counter.

6. Where the recommended timing cycle exceeds 30 cycles, which is standard on most controls, additional time is easily added to the weld time circuit, such as

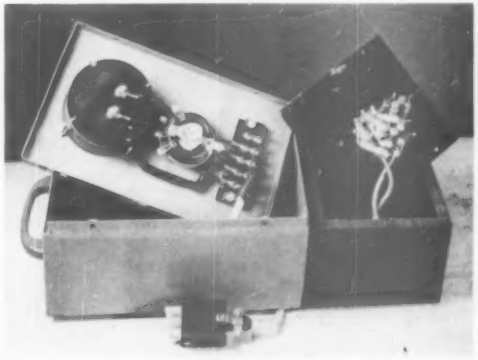


Fig. 4 Current meter and time box (inside view)

with a "time box" shown in Fig. 3, with exposed inside view shown in Fig. 4.

7. Refer to a recommended spotwelding schedule, such as shown in the A.W.S. *Recommended Practices for Resistance Welding*, or use the schedule as per Fig. 1.

8. Prepare a chart combining all of the information in items 2, 3, and 4. See Appendix I. This chart is generally posted within easy view of the welding-machine operator and can be observed by supervision, inspection, engineering and production personnel.

9. Set the machines up to these recommended values and observe the current meter readings. If the meter reads correctly as shown in the chart mentioned in Step 8, proceed with production welding, observing occasionally the meter reading.

Figure 5 shows the production setup of the steps covered in compiling the information in Appendix I. To the left of the operator is the current meter, securely fastened on top of the Nema-type S3H control. To the right of the operator, and within easy view and access,

Fig. 5 Production application showing meter and charts

are the charts shown in Appendix I and items 2, 3 and 4, mounted in one large picture frame.

Regardless of the type of electronic control, the required information can be compiled and the machine tied in to a recommended schedule, such as shown in Fig. 1, that is within the capacity of that machine, depending on available pressure and current output.

PART II—MAKING A PRODUCTION SETUP

Upon obtaining the necessary information and tying it in to a definite schedule, as shown in Appendix I, the operator, without any special instructions, is ready to proceed to make his production setup. In many instances in the past, without this information and with no available meter the average operator would use the trial method, whereby with reference to personal records, such as his "butcher book," he, the operator, determines what pressure gage setting is required for welding, what tap and/or heat control setting is best and what weld time is required. He then proceeded to make sample welds with short ends of material thicknesses. On these short pieces, the operator, to minimize "spitting" or metal expulsion during the weld cycle, uses a lower heat setting, generally of current and/or time, than is used on the finished product or production order. The operator again using his own personal judgment adjusts the heat settings to what he thinks is producing as good a weld as his samples indicated. Likewise, the testing of the weld in the past has been the "hit or miss" method, whereby a hammer and chisel or a twist test was used to determine the degree or quality of the weld.

Taking a specific example from Appendix I, for two thicknesses of 0.125 thick or for any thickness combination averaging this combination of a total thickness of 0.25 inch, the recommended production welding settings are:

Weld current	14,600 amp.
Meter reading for weld current	490
Short-circuit current through copper	17,200
Meter reading through copper	575
Meter range switch	2
Heat control dial (approx.)	35%
Tap setting	High 4
Weld force	1,500 lb.
Gage pressure, psig.	30
Weld time, cycles	59
Hold time, cycles	30
Electrodes	one-$^7/_8$ in. D flat and one-$^7/_8$ in. D —6 in. R spherical radius face

Without wasting time or material, the operator sets the machine to the proper physical location to allow the welding fixture and/or the parts to be welded without any interference. This he would have to do regardless of what machine settings he would use. Thus, nothing extra is added. Instead of using sample thicknesses, a piece of copper, generally equal to the thicker thickness of one of the pieces being welded, is put between the electrodes and the machine is fired one or two times after the heat-control settings and/or tap settings are made, and the weld time and the gage pressures are set as shown on this particular illustration. The meter should read 575 amp. on Range Switch 2. If it does not read this value, the heat-control setting is adjusted until the meter reads 575 amp. through the copper piece between the electrodes.

Remove the copper piece from between the electrodes, put in the parts to be welded and make the first weld, after setting the meter on 480 by means of the pointer stop to permit observation of deflection upward. The meter should read 490 upon single or successive welds. If this procedure is followed, the minimum nugget diameter of this weld will be $^5/_{16}$ in. and the minimum shear strength of any one of a series of spot welds will be 4000 lb. If only one weld is required and engineering design conforms to recommended overlap

and edge distances, the shear strength of the weld will be no less than 4800 lb.

Because of the long-established practice of testing welds to destruction, a test fixture is used for two thicknesses of 0.094 or heavier. Below this thickness, the AMERICAN WELDING SOCIETY peel test method is used.

The welds are made in rapid succession and the last weld marked or identified. This weld is then put against the chisels which straddle the weld and the chisels then pushed into the test specimen by means of the 12-ton hydraulic jack. This size jack was found adequate for two pieces of $^1/_4$-in. thickness. This test, called a Separation Test, quickly determines the weld nugget diameter of the third weld, and if the minimum diameter is met, the operator proceeds with his production welding. This fixture costs less than $300, weighs approximately 150 lb., and can be set in an area near the welding machines within ready access to any number of operators. In numerous checks and time studies made, no more than five minutes' time is required for this test, usually performed at the beginning of each shift, change in setup, or at the discretion of the inspector. This separation test fixture eliminates the necessity of pull tests and can be performed satisfactorily by shop welding personnel. Pull tests on steel generally involve the use of test machines which are usually located in a laboratory not in the immediate vicinity of the welding production. Pull tests are usually made on a single weld, and thus consideration of by-pass effect is omitted.

PART III—DETERMINATION OF WELDING SCHEDULES (FIGURE 1)

Over a period of years, many types of recommended welding schedules were tried. The one found most suitable is the one shown in Fig. 1. It was found that standard flat and spherical radius-faced electrodes could be used instead of the truncated type originally recommended, with much longer electrode life obtained. This extended life was partially obtained by standardizing on the distance between the bottom of the coolant hole to the tip surface in contact with the work of $^1/_2$ in. instead of $^3/_4$ in. These electrodes are now available from all leading suppliers and can be seen in some of their catalogs. This has followed a pattern rather than set it, and cooperation with leading electrode suppliers aided in establishing a very reliable electrode design which has been proved in over one year's time in many production sections on several thousand different spot-welding applications.

Electrode and holder standards have now been established, and parts are being supplied to these standards at no additional cost. Information on standard electrode and holder designs is being compiled to show available types with their limiting dimensions. This will be shown on application sketches now in the course of compilation for Engineering Design Standards Sheets as an aid or guide to the design engineer. Electrode suppliers often illustrate these applications in their catalogs.

PART IV—MACHINE APPLICATIONS OF THE CURRENT METER

While the procedure of adapting any specific resistance-welding machine, as outlined in Part I, to spot-welding of mild steel, there is no limit to the material to be spotwelded. Temporary standards have been established for aluminum alloys, stainless steels and copper alloys, and production setups are made in exactly the same procedure as outlined for mild steel spot-welding. It has been found advisable to use five or more cycles of weld time in order to obtain sufficient meter deflection. It is not suitable for measuring current at one-half cycle timing. The meter is inexpensive and the cost is a very small fraction of the welder and control cost. It is possible to purchase standard controls having the meter as an integral part of the control.

In most cases of over 150 known applications, the separate mounted meter has been preferred. In production setups where a bank of welding machines are located, it has been found economical, on highly repetitive work, to have one meter serve as many as 12 machines. This can be done by using a Jones-type plug which is tied in to a 110-v contactor relay on every machine. Each of the 12 machines has its own current transformer permanently installed, and the meter disconnected by simply separating the male and female parts of the Jones plug. The male part is shown to the left of the meter on Fig. 4. The combined cost of the Jones plug and contactor relay is about 10% of the total cost of the current meter. The purpose of the contactor

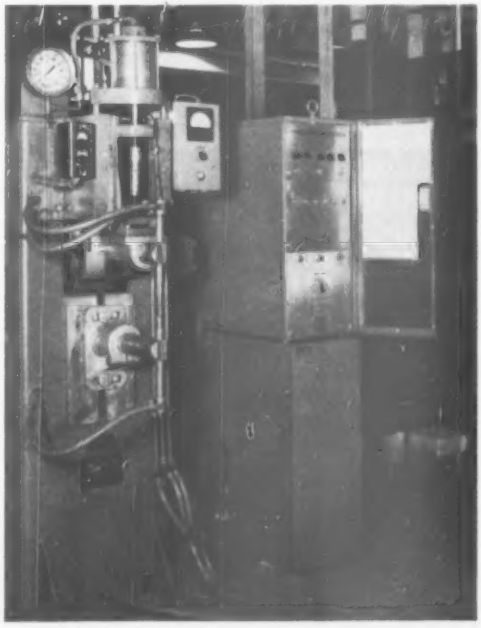


Fig. 6 50-kva Spotwelder showing meter and charts

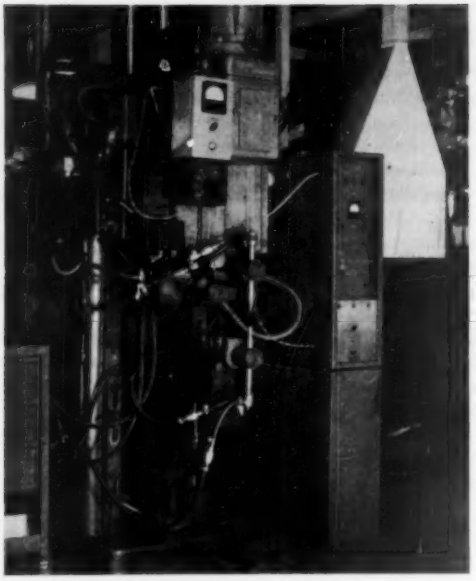


Fig. 7 250-kva. Spot-projection machine showing meter and time box

is to short circuit the current transformer when the Jones plug is disengaged. Thus, if a spot check either on the establishment of a proper setup or as an inspection check is required, this arrangement is entirely satisfactory. The meter should always be located out of the magnetic or inductive loop of the welding machine. The meter has been calibrated for the $^1/_{16}$-in. thick steel case shown in Figs. 2 (*b*), 3 and 4.

Figure 6 illustrates a 50-kva. horn-type spotwelder with the meter mounted parallel to the face of the machine. The charts on the open door of the control

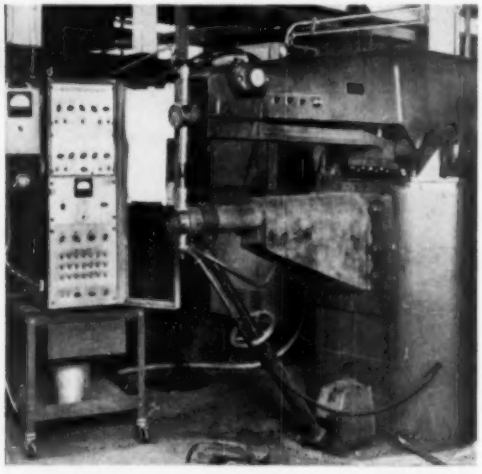


Fig. 8 400-kva. Rocker-arm spotwelder showing meter, time box and charts on portable electronic control

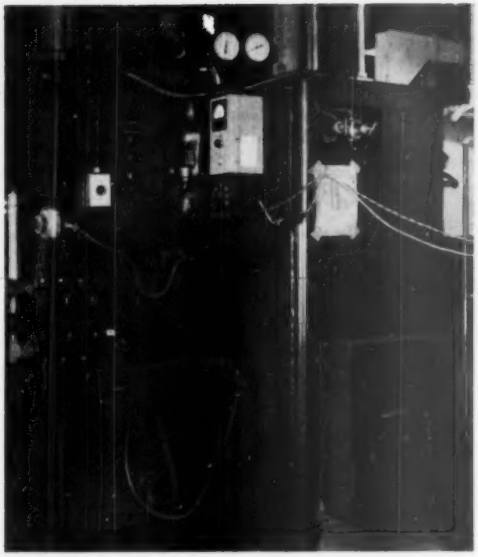


Fig. 9 400-kva. Projection press showing side mounting of meter and time box

were obtained by the procedure outlined in Part I. Sixty-cycle timing is available on this Nema-type S3H control and no further extended time range is necessary.

Figure 7 illustrates a 250 kva. combination spot-projection welder with the current meter and time box, shown in Fig. 3, mounted within ready access of the welding operator.

Figure 8 illustrates a 400-kva. deep-throat, rocker-

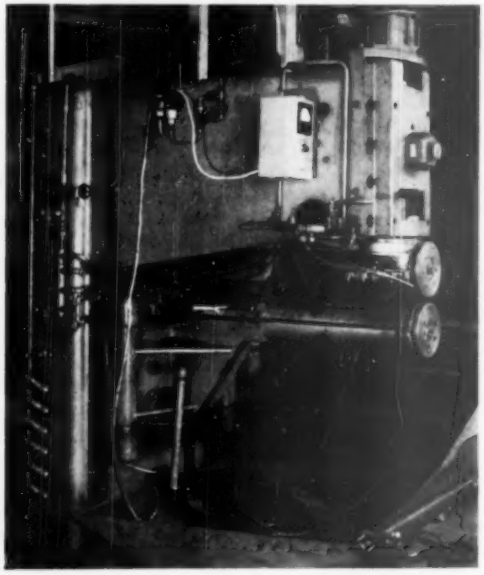


Fig. 10 300-kva. Seam welder showing side mounting of meter

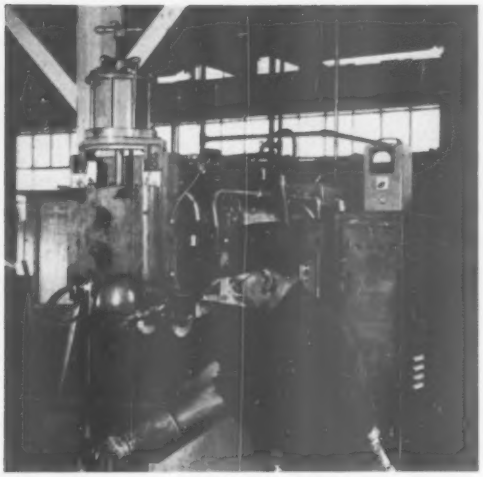


Fig. 11 250-kva. Deep-throat spotwelder showing accessible location of meter and charts

arm-type of spot-welding machine with the current meter and time box mounted on the side of the control which is portable. The machine charts are posted on the inside of the control door.

Figure 9 illustrates a 400-kva. deep-throat, projection-press welding machine with the current meter and time box mounted on the flat side of the machine outside of the "welding loop." It is still within ready access of the operator.

Figure 10 illustrates the application of the current meter on a production seam welder. It is less than 1 ft. from the face of the machine and is within plain view of the operator.

Figure 11 illustrates a production setup on a deep-throat spot-welding machine necessitating a deep-throat opening for clearance purposes. Here the current meter is securely fastened to the Nema-type S3H control which has been adjusted to long weld time range by adding time selection switches. The recommended welding schedule may be seen to the left of the machine.

Figure 12 illustrates a production projection welding setup with the current meter mounted to the right of the control. This job is highly repetitive and the operator can observe the meter reading with no difficulty. Here, without a recommended projection-welding schedule, the meter is used as a reference point for a current setting which has been proved to produce quality projection welds.

PART V—ADJUSTING TIMING CONTROLS TO "LONG-TIME"

As mentioned in the Introduction, the cooperation of the various departments involved, through the efforts of an established committee, resulted in this company-wide method of obtaining consistent quality welds. After the welding data began to take shape, the Electronic Control Engineering Department was requested

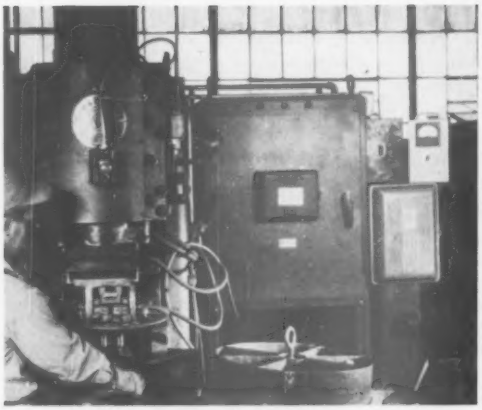


Fig. 12 250-kva. Projection welder showing visible accessibility of current meter

to supply information for adjusting the controls to required higher weld-time cycles which would apply to all of their own types of controls, both synchronous and nonsynchronous. This was done and this information is now available throughout the Corporation's electrical maintenance sections. In the case of synchronous controls, external resistances were added in series with the weld time circuit. The known values of resistances in ohms per cycle were calculated and radio-type resistors as shown connected in Fig. 4 were added in a small micarta box; hence the name "time box." There are various ways of accomplishing the extension of, what was prior to 1949, standard timing of thirty cycles. Another way was to add selector switches of 30 or 60 cycle duration. This would require the operator to add the number of switches to a given recommended timing, and was found objectionable. However, today, standard controls with 240-cycle timing are now available at no additional cost.

PART VI—JOB RECORDS

A universally accepted form of job record had long been desired. With the aid of the Process Committee, a form was developed, and is now in use throughout the Corporation. This job record is called a Resistance Welding Job Record and is intended for spot, seam and projection welding. Sufficient data is on both sides of the form, so as to obtain concrete information which can be used as a reference starting point. This form is generally made out in duplicate; one copy stays in the welding group and one copy goes to the supervisor, who in some cases is the foreman and sometimes the welding engineer. The use of this Job Record Card, as covered in the Process Specification, reads: "If the job is repetitive and cannot be covered by the recommended welding schedules (Fig. 1), a Job Record Card, (Form No. 24387), shall be made in duplicate by the person responsible for the welding setup. One copy of this record shall be available to the welding-machine operator and the other copy kept in a master file."

"Parts not in compliance with minimum requirements for overlap, edge distance and electrode accessibility shall not be welded without approval of the Welding Supervisor. A Job Record Card shall be made of any setup made under these substandard conditions."

Further interpretation of the above-quoted statements is that no job record is required if the design meets the minimum requirements shown on the schedules in Fig. 1, since the chart shown in Appendix I is always within sight of the operator, inspector and supervisor. A glance at this chart and checking the machine settings and the meter reading will indicate quickly whether or not the machine is properly set up to the required values. The Job Record form is on a card 5 x 8 in., with the information on the upper half of the sheet on one side and the lower half of the reverse side.

PART VII—CURRENT TRANSFORMER RATINGS

For most applications, two sizes of transformers have been found practical, and both are applicable on 220, 440, 550 and 2300 v. primaries. One size has the following ratios: 200–400–600 to 5 amp. The other size has the following ratios: 300–600–1200 to 5 amp. Thus, with the meter which is a standard 5 amp. meter equipped with a back pointer-stop, either a direct-reading meter, such as shown in Figure 2 (*b*), or a meter with a 0 to 5-amp. scale is used. In the case of the first transformer with 200–400–600 to 5 ratio, on meter ranges 1, 2 and 3, respectively, the meter multiplier on the direct reading scale will be 0.33, 0.67, and 1. On the second transformer, which is the one most commonly used, with ratios of 300–600–1200 to 5, on meter ranges 1, 2 and 3, respectively, the meter multiplier is 0.5, 1 and 2 in the same order.

PART VIII—ADVANTAGES

With this developed plan of adapting a current meter to a resistance-welding machine on spot, seam and projection welding, the following advantages are cited to substantiate that a practical method for obtaining consistent resistance welds has been made available:

1. The use of a recommended schedule (Fig. 1) with the aid of the current meter permits a quick check at any time during the welding operation of seeing what actual current is being used to make that weld. Since the current is the most important variable in the welding operation, the meter indicates what current is being used to make the weld; hence a means of indicating whether or not consistent quality welds are being obtained. Hitherto, it has been purely guesswork as to the current being used to make a weld.

2. The meter takes into consideration throat opening and depth, and the presence of steel in the throat of the welder. Recommendations cover what the meter reading should be when making a weld, and the operator is shown how to make the proper adjustments to obtain the proper meter reading.

3. The best known guarantee of a sound weld, because years of study and testing have developed a welding schedule which will produce a sound weld of known minimum strengths.

4. It simplifies the welding operation, because with minimum amount of training the operator can be taught to set up jobs to the meter from a given chart.

5. It minimizes setups and personal opinions of operators as to which heat tap, time setting or pressure setting gives the best results. On certain thin thickness ranges, it is possible to have one machine setting take care of four or five different thickness combinations.

6. It will permit a good, sound job record to be taken of other welding operations, such as projection and seam welding, where established or proved schedules are not now available. A job record form for corporation-wide use is now available for this purpose.

7. It will enable establishment of corporation-wide standards in spotwelding, along with a corporation-wide process specification now in use.

8. Minimum or no spitting or expulsion of metal during the weld will be obtained if the recommended welding values are followed.

9. It is an inexpensive addition to a welding machine. The current transformer and meter can be purchased from a welder manufacturer as part of the equipment.

10. The electrode standards being recommended will save much money because of the proven longer life which they have over odd shapes and sizes used at random throughout the Corporation.

11. Where welding of mild steel is concerned, it will simplify information in purchasing welding equipment in the future. With known requirements for welding, and proper consideration of all factors involved, machines of proper capacity can be purchased. Too frequently over-sized capacity is purchased to make sure the machine will be "big enough."

12. It is planned to adapt this plan to all resistance welding in general, including mild steel, aluminum, stainless steels, copper alloys and the processes of spot, seam and projection welding, where they apply.

13. As more experience in production welding is gained, the plan will become even more flexible.

14. It gives the electrical maintenance department a means of checking the welding maching operation. The meter will indicate variation in machine output at a glance.

15. On two or more machines electrically interconnected, it serves as an excellent check on correct welding currents being used, because no two machines of identical kva. rating have the same current output for the same adjustments of the tap changer or heat control On one example in particular, where two machines are mounted face to face, welding currents are established so that the current from the second machine is higher than the current on the machine making the first weld. The meter readings are not necessarily identical.

Thus, the second machine is set to compensate for the by-passing effect of the first machine's welds, assuring to a greater degree that identical welds are produced from each machine.

16. A suggested procedure for adapting spot-welding machines to long-time weld schedules has been prepared and distributed throughout the company where this plan is used.

17. Included among the things this plan will do are a couple of things it will NOT do. Among these are:

(*a*) This method of welding to a recommended schedule with the aid of a meter will not adjust itself to tip variations, i.e., mushroomed tips, odd shapes, etc. However, with the recommended tip combination, generally a spherical radius tip and a flat tip on any shape of tip, maximum tip life can be obtained.

(*b*) This method will not automatically adjust the welder in case of variations such as line voltage, steel in throat, by-passing effect, etc. Such a method to do this automatically would be very expensive and require constant welding and control supervision. In the case of lower output, due to decreased line voltage or increased reactance because of the steel in the welder's throat, the meter will indicate the fact that lower current is being obtained, but it will require the operator to make proper adjustment.

(*c*) It will not compensate for improperly designed jigs or fixtures which permit by-passing or grounding to the frame of the welding machine. Properly designed tools is the joint responsibility of the tool and welding supervisors.

PART IX—CONCLUSIONS

The conclusions that this plan offers a practical method for obtaining consistent resistance welds are:

1. Its wholehearted acceptance wherever it has been introduced, particularly where consistent quality welds are a requisite.

2. The meter and transformer are an inexpensive addition to any spot, seam or projection-welding machine and serve many useful purposes, as cited in Part VIII.

3. The plan of tying in the meter and transformer is simple and requires less than 4 hr. per machine to obtain the full information as outlined in Part I, including all the arithmetic involved in the Appendix.

4. It is easy to sell to the operator, foreman, welding engineer and the design engineer. The schedules, as in Fig. 1, are a considerable aid to all concerned and simplify the process and the design. The design engineer has some recommendations to follow, adherence to which will guarantee him certain minimum strengths.

5. It is possible to decrease the number of spotwelds and even to use one spot where formerly a minimum of two or more were required, since consistent quality welds can be obtained by this plan. Lesser number of welds also means lower manufacturing cost, less distortion, stronger single welds and longer electrode life, since minimum recommended edge and overlap distances are observed by engineering design.

6. It is possible for welding machine manufacturers, such as R.W.M.A. member companies, to provide with the machine and controls the current meter and transformer, and even the time box if its extended range feature is desired. The meter and/or the time box can be mounted on the frame of the welding machine as easily and as accessibly as pressure regulators, pressure switches and other accessories. The necessary charts can be provided and charged for as part of the equipment or rendered as a customer service.

7. The welding operators who have become familiar with this plan welcome the application of the schedule as shown in Appendix I. It eliminates guesswork on his part and narrows down the possibilities of obtaining poor welds to electrodes, fixtures, etc.

8. It simplifies the machine and control, and eliminates the need of pulsation-timing controls, because comparison of the single impulse weld time cycles with published pulsation time schedules will show the single time welds to be faster. For example, one schedule for two pieces of $^1/_4$-in. thickness on pulsation timing for 2 to 4-in. spacing requires 18 pulsations of 20 cycles on and 5 cycles off, or a total weld time of 450 cycles as compared with 153 cycles for 4-in. spacing, or 230 cycles with $1^3/_8$-in. spacing as taken from the recommended schedules shown in Fig. 1.

9. The plan can be used on 1 machine, on 12, or on 100 machines. It is not limited to any particular type of spot, projection or seam-welding machine, or 60-cycle, single phase a.-c. equipment. The meter cannot be used on stored energy, half cycle or three phase to single phase, twelve-cycle frequency. Single-phase, 60-cycle machines are the most widely used of all resistance-welding machines.

10. It aids in qualifying equipment to Army and Navy specifications for mild steel, as these specifications usually require minimum weld nugget diameter and/or a minimum tensile-shear strength. These can be met if the schedules shown in Fig. 1 are followed.

11. The meter has not been used on any gun welding applications up to the present time, as it has not been deemed necessary. On the short time cycles between 9 and 28 cycles, or between 0.036 and 0.078-in. thicknesses, the meter would work on a gun welder without any additional timing increase. Most gun welders are used for transportability and long leads between the current transformer and the meter would be required, in order to keep the gun cables and yoke free of any obstruction.

12. The principle and use of the meter is not limited to the schedules, or to a maximum of two pieces of $^1/_4$-in. thickness. Several applications involving $^3/_8$ and $^1/_2$-in. thicknesses and using 480 cycles of single impulse timing are in production.

13. If the schedules shown in Fig. 1 and the meter tied in as shown in Appendix I are followed, clean welds are obtained with no flash, spitting, or metal expulsion. If these occur, a glance at the meter might indicate

APPENDIX I

Precision Rocker-Arm 250-kva. Spotwelder, MO-10 (W) Tool #58232

Two Thicknesses of	Welding Current (amps.)	Meter Reading for Welding Current	Short Circuit Current through Copper (amps.)	Meter Reading through Copper	Meter Range Switch	Heat Control Dial (approx.)	Tap Setting	Welding Force (lbs.)	Gauge Pressure (lbs.)	Weld Time (Cycles)	Hold Time (Cycles)	Electrode Diameter and Shape Combination
.036	7,000	230	8,200	270	1	35%	Lo-1	250	5	9	10	1/2D - 2" rad. face and 1/2D flat or 5/8D - 2" rad. face and 5/8D flat.
.050	8,400	280	9,900	330	1	40%	Lo-1	400	8	14	20	Same as above.
.064	9,200	310	10,800	360	1	45%	Lo-1	600	12	21	20	" " "
.078	11,400	380	13,400	450	1	50%	Lo-1	800	16	28	30	" " "
.094	11,400	380	13,400	450	2	30%	Hi-4	1050	20	37	30	1 - 7/8"D Flat and 1 - 7/8"D 6" rad. face.
.109	14,600	490	17,200	575	2	35%	Hi-4	1300	25	47	30	Same as above.
.125	14,600	490	17,200	575	2	35%	Hi-4	1500	30	59	30	" " "
.156	19,200	330	22,600	380	3	40%	Hi-4	2200	42	93	45	" " "
.188	22,200	370	26,100	435	3	47%	Hi-4	2700	52	130	45	Above combination or 1 - 1¼"D Flat and 1 - 1¼"D 6" radius face.
.250	28,000	470	33,000	550	3	55%	Hi-4	3700	70	153	90	1 - 1½"D Flat and 1 - 1½"D 6" radius face, single welds only.
.250	28,000	470	33,000	550	3	55%	Hi-4	3700	70	230	90	Same as above. Use 230 cycle timing on second or more welds.

NOTES ON WELDING SCHEDULE

1. SHORT CIRCUIT CURRENT THROUGH COPPER OR METER READING THROUGH COPPER.
These columns are to aid in setting up the machine for the required welding current. If this value is obtained while firing the machine through copper, it will give approximately the correct welding current. Meter readings should be established with one division deflection of the pointer. If there is no pointer deflection, increase the heat per cent until recommended reading is obtained.

2. WELDING CURRENT OR METER READING FOR WELDING CURRENT.
These are the values that the machine must be set for when the welds are actually being made. If more than one weld is made, the machine must be set to obtain these values for the spot weld which has the most metal in the throat of the machine. Spitting or expulsion of metal should not be tolerated. If this occurs, decrease Heat Control dial setting by 1 or 2 points, until spitting or expulsion stops.

3. APPROXIMATE HEAT DIAL PER CENT.
These values are only approximate and are figured with the throat opening and throat depth of the machine set where they are most likely to be used. They are given to aid in setting up the machine. If the throat opening or throat depth of the machine is increased, the Heat Dial per cent will have to be increased to obtain the correct current during welding. Also, if metal is placed in the throat of the machine during the welding cycle, the Heat Dial per cent will have to be increased to obtain correct current during welding.

4. ELECTRODES.
Use the electrodes given in the chart above for the various thicknesses of material. Do not file the electrodes in the machine. If the electrodes become worn, replace them with new or refaced electrodes.

5. THICKNESS COMBINATIONS.
When two unequal thicknesses are to be welded, use the machine settings for the average thickness. For example, in welding one thickness of .125" to one thickness of .188" the average thickness is .156", and settings for this thickness are used. See Weld Schedule Chart for other dissimilar thickness combinations.

6. HOLD TIME.
The hold time shown for each thickness should be rigidly maintained. Insufficient hold time results in greatly weakened welds.

If something goes wrong with the machine or welding schedule settings cannot be maintained, notify the supervisor at once.

whether or not an increase in current has occurred, or if not, the material is scaly or oxidized. Oily material has been successfully welded with this plan, but scaly or coated steels, because of their detrimental effect on electrode life, have been ruled out. However considerably less metal expulsion even on coated steels is obtained with the long time single-impulse welds.

14. The application of this plan has expedited the acceptance of a Westinghouse Corporation-wide process specification for mild steel; has enabled standardization of electrodes, wheels and holders; has expedited development of a tool to restore the electrode contour without removing the electrode from the holder in the machine; and has aided the design engineer to conform his designs to the recommended flanges and overlaps. The production and manufacturing people who are using this plan are convinced of its merits and they have asked the design engineer to cooperate in standardizing his designs as much as possible.

15. In not one case of over 150 installations has the current meter and transformer been removed for any reason whatsoever.

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Better Welding at Lower Cost

A general discussion of the various factors which determine quality and cost of welding and hints for securing improved quality at lower cost

by Lew Gilbert

INTRODUCTION

THIS topic was conceived with a definite need in mind: the need for a frank, down-to-earth discussion of the various factors which determine the quality and cost of your welding.

Because the matter of costs seems always to suggest long columns of figures and other such data, the title of this paper may have been misleading. At the risk of disappointing some of you (or perhaps pleasing many of you) I do not intend to go into a highly technical discourse on costs or procedures. I intend only to discuss with you some of the possible reasons for poor welding which—because they cause failures which necessitate repairs, or poor appearance which may require excessive chipping and grinding, or rejections which mean additional outlays of time and materials—thus increase your welding costs. I do not even claim to have all the solutions for the problems we will discuss. I hope that we will-collectively-be able to suggest ways of improving the situation. It has long been my contention that "fixing the fault is cheaper than fixing the blame."

Most welding costs result from a combination of time, labor and materials—as they do in any type of manufacturing operation.

In the case of welding however, other factors must enter into any discussion such as this. What these factors are—and the order of their importance—has long been the subject of considerable controversy.

DESIGN FOR WELDING

Many of the most significant costs connected with welding occur long before actual operations begin. In some cases they start with the attitude of top management toward welding. In the larger fabricating plants perhaps the number of one cost factor is the design engineer. If he is not adequately equipped with a comprehensive background of welded design, this will surely show up in the final cost of the product. In the thousands of plants where welding is used primarily as a maintenance tool, costs are determined by the welding "know how"—or lack of it—on the part of supervision, which in turn is reflected in the workmanship of operators. In the job shop—which some people consider the proving ground for welding because so many outsiders judge welding standards by what these shops do—costs are decided by a combination of all these factors. In too many cases when welding costs are investigated, the question which is most usually of greatest importance is, "Have we done this job in the cheapest possible way?"—not, "Have we done this job in the best possible way—at the lowest possible cost?" To properly cover the fields where possible

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savings may be effected, we will discuss briefly those major factors which tend to reduce welding costs.

CHOICE OF MATERIALS

When we have solved the problem of design for welding, our next step is to decide what materials to use. Whenever possible of course, these should be within an analysis range which will not normally require unusual welding procedures.

Since size of plate not only directly affects amount of material and also requires greater quantities of weld metal, it is more economical to reduce plate thickness within normal strength requirements. Wherever possible, design should include the use of standard shapes which lend themselves more easily toward material cost savings.

WELDING METHOD

The method, of course, must be regarded as one of the most important factors determining welding costs. Should the job be done by oxyacetylene, arc, resistance inert-arc or some other welding method? Should it be a manual operation? Should it be semiautomatic or should it be fully automatic? Companies which have Research or Experimental Departments are indeed fortunate. These have every conceivable type of welding and auxiliary equipment and are able to set up and run a given job using as many methods as they wish to try. Not only the method, but also detailed procedures are worked out for transmitting to the welding departments concerned. Most manufacturers of welding equipment have their own Research Departments and are in a position to give users helpful information, thus saving them considerable time and money. Manufacturers' representatives or jobber sales engineers are usually in a good position to help the user of welding. Not only does he have the cooperation of his own company, but over a period of time, he has accumulated a worth-while knowledge of how other companies are doing similar jobs. It is good practice on the part of welding users, large and small, to take advantage of this type of assistance.

JOINT DESIGN

It is not difficult for a designer to determine the required strength at a given joint. Once joint design is determined however, it becomes a matter of importance to fabricating costs what type of welded joint will achieve the desired strength. Welded joints are made in two ways; either by making a joint which consists largely of fused base metal or one consisting largely of deposited filler metal. The most economical weld of course, is one which requires the least edge preparation, the minimum amount of deposited weld metal and which can be made at maximum deposition rates.

Designers familiar with types of joints and their load characteristics select the one that will result in minimum deposited weld metal and minimum edge preparation.

For example, if a butt weld with 100% penetration is desired, several possibilities are available. The square butt joint involves no edge preparation but it may have to be welded from both sides. This joint requires the least amount of deposited metal.

The single vee joint requires more preparation and more electrode than the square butt joint.

With the double vee joint cost of machining is higher than the single vee. However, it requires only half the amount of electrode for the same plate thickness.

In selecting the most economical joint, therefore, both the cost of welding and the cost of machining must be determined and the selection made for various types of joints and for various thicknesses of plate according to these basic cost figures.

Important also in specifying the least costly joint is it's location. Designers must avoid calling for welds in inaccessible places. Familiarity with the welding process to the point of actually doing some welding will help those responsible to avoid putting welds in spots which cannot be reached with an electrode.

EDGE PREPARATION

Another factor affecting welding costs is the preparation of plate edges to be welded. Selection of the joint to be used and instructions for beveling or cleaning plate edges may originate with the design engineer or farther along the line. It is a well-known fact that proper plate-edge preparation is "half the battle." The worse the preparation, the higher the welding cost. In some cases, poor preparation or careless beveling is responsible for weld failures.

One of the greatest savings in automatic welding is effected by reducing the cost of plate edge preparation. For instance, with submerged arc welding, square butt welds may be performed on thicknesses up to $^3/_4$ in., requiring no bevel, and only one pass on each side. The bevel, of course, will determine the amount of weld metal to be deposited, with the accompanying time and cost required. Excessive beveling is an unnecessary waste of money. On the other hand, insufficient beveling can be harmful. The operator must be able to get the first pass down into the bottom of the "V" without any trouble. The angle of the "V" must be sufficient to enable the welder to fuse the bottom, sides and filler rod into one homogeneous mass.

Before leaving the subject of plate preparation, it should be emphasized that considerable attention must be given the method used in making the bevel. In some cases it might be cheaper to use a saw, as in the case of light gage aluminum, copper, etc. In some cases, it might be advantageous to use a planer, as in the case of a "U" or "J" groove in stainless steel. We usually think of a flame beveling operation, and we must decide whether a manual flame beveling job is the answer, or whether the job should be done by automatic flame beveling. In the case of a double bevel, should we be

satisfied with beveling from one side at a time, or should both sides be beveled simultaneously? In this case, as in the case of welded joints, procedure data should be developed and passed on to those responsible. Such data should specify the equipment to be used, the size nozzle, the oxygen and acetylene settings, speed in inches per minute, etc.

POSITIONING

The use of positioners for weldments has done much to increase production, reduce costs and promote safety. We all know the old story of larger electrodes, higher currents, fewer passes and higher quality which result from using positioners. It does not seem logical that so many plants still fail to realize the substantial savings effected. The cost of positioned welds runs less than half as much as out-of position welds. One of the benefits of using positioners is the elimination of costly crane tie-ups. Cranes are specialized machines adapted to loading, unloading or general shop moving operations. It is too extravagent to saddle these expensive devices with relatively simple positioning operations which can be performed much more efficiently with other equipment. In talking about positioners, I mean to include power-driven rollers such as are used in tank fabrication.

The advantages of using jigs and fixtures are obvious. Even for very small subassemblies and when production does not run very high, it is usually economical to do such jobs in special fixtures, usually the rotating type. One time and labor saving use of jigs and fixtures is a rather simple one which can double or nearly double an operator's production. It consists merely of having two duplicate jigs with a helper doing all the loading and unloading. Too many welding operators spend too much of their time doing other things beside welding. Generally speaking, an operator is a highly trained man and earns a fairly high hourly rate. Why should he spend half of his time loading and unloading parts or manipulating the work to be welded? If he can produce a certain number of units in an hour doing all the work himself, it is obvious that with a helper and another jig, he should be able to do twice as many. The helper sets up the job in one jig while the operator is welding the job in the other. The only cost connected with this doubling of production is that of one jig and one helper.

The use of quick-acting toggle clamps also deserves mention. It is a waste of time and money to use other types, when quick-acting toggle clamps cost very little and account for such savings. Clamps, of course, run all the way from small vise grip clamps for light work, to large pneumatic clamps for use on work ranging from small tank fabrication to railroad car construction.

PROCEDURE

After the method is determined, procedure data must be developed. Here again, in the larger companies, this might be handled by the Research or Experimental Department. In smaller companies, this data is usually developed in the shop. By welding procedure, we refer to such factors as the number of passes, electrode diameters, current settings, position of welds and sequence.

At this point, I would like to describe briefly how some larger fabricators handle the phases thus far covered. After design is established, drawings are made, checked by the Engineering Department, and turned over to the Methods Department. This section determines the method of manufacture. Where welding is involved, Welding Specialists in this department study the case thoroughly and recommend the particular welding method to be used. These specialists draw partially on their past experience, partially on equipment manufacturers' recommendations and partially on their experimental findings in the shop.

After the method is determined, drawings and recommendations go to the Standards Department. Here detailed procedure is worked out for each operation. In the case of an arc welded joint, Standards develop details covering the bevel, size electrode, number of passes, current settings, reinforcement, etc.

The information is translated to welding procedure data sheets, which consist of sketches and tables pertaining to various joints, thicknesses, etc. These procedure data sheets then go to the Welding Supervisor, who checks the information and goes over it with the Welding Foreman concerned. They transmit instructions to the welding operators along with any additional suggestions regarding technique which may seem advisable. The results are gratifying. Each operator knows exactly how the job should be done, and every operator supposedly does the same job in the same way. There is no doubt that standardization pays big dividends.

OTHER COST FACTORS

Among the various basic factors which tend to increase welding costs is the common problem of excessive weld metal. Not only does this build up increase time and material costs, but also grinding and finishing costs. In some cases it may even set up possible notch sensitivity in a joint, which could result in serious weld failure.

Overwelding in other respects is often costly also. Frequently a series of small welds will be as effective as a long continuous weld; a small continuous weld equally as good as a series of large intermittent welds and a 6-in $^1/_4$-in. fillet weld equivalent in strength to a 3-in. $^1/_2$-in. fillet. The smaller weld will require only half as much weld metal and can be deposited in half the time.

In the interest of economy it is sometimes advisable to use castings and forgings in the fabrication of a weldment. The decision in such cases depends on the number of weldments to be made and the cost of producing necessary component parts. The use of efficient cutting and forming equipment, and of preformed shapes whenever possible materially reduces fabricating costs.

Other important cost problems involve control of distortion, close cooperation between engineering and shop personnel, proper use of the right kind and quantities of equipment, type of fit-up—good, bad, or indifferent—the use of subassemblies whenever possible, careful inspection of equipment and workmanship and efficient shop layout and material handling. Since the latter is of such importance that it merits separate treatment, let us discuss it in somewhat greater detail.

SHOP LAYOUT AND MATERIAL HANDLING

Now that we have brought our welded product this far, we enter another most important phase—in fact, actually two phases, which are so interdependent that they can be discussed at one time. The ideal weld shop should be set up so that there is a straight-line flow of production, or the closest possible approach to it. If steel and other materials can be brought in at one end of the building and proceed on a straight-line basis through shearing or cutting, plate edge preparation, forming, welding, testing and finish operations, and then go right out the opposite end of the building, costs are naturally going to be much lower than they would in a shop where this system does not exist. In the well laid out shop, considerable thought must be given to the location of welding machines and other equipment. There must be ample working space for equipment operators, and adequate aisle space for easy trucking. The plan for material handling must insure easy, uninterrupted flow of material from station to station or from fixture to fixture. If equipment is poorly located, too much time is lost in handling and crane lifting, and oftentimes bottle-necks are created which entirely cancel out the efficiency of the best machines and fixtures.

There are, of course, certain factors which combine to determine the best type of layout. In many plants which were erected too many years ago, there just is not space to do all the things that should be done. However, in these old plants, equipment can usually be shifted around to make for a more efficient flow of materials. Some plants could stand a good, old-fashioned housecleaning any way which would result in more space, if nothing else.

In the case of large items such as heavy machinery, it is often feasible to have separate welding shops, each fabricating a subassembly. These are fed into an Assembly Department whose job is to weld the subassemblies into an integral unit.

In the case of parts or subassemblies which are too heavy or too large to handle on roller conveyors, it may be necessary to have a series of jib cranes to supplement overhead traveling cranes. In too many plants, overhead cranes have a way of getting tied up, thus retarding production or movement of subassemblies which are completed and ready for transfer. The efficiency of welding operators and other workers is kept at a maximum when parts are delivered to and removed from the various stations with no loss of time.

THE HUMAN ELEMENT

All of the factors we have discussed so far are important in determining the over-all efficiency of our operations and hence our final welding cost. A more human side of this picture however, operator safety and comfort should also be considered. Most of us are concerned with management, engineering or supervision. Unless you have actually been out in the shop putting in a hard day's work, much of the time covered with dirt and sweat, you may have a little difficulty appreciating how much these things mean to the operator's state of mind and his productivity. Safety is a subject all by itself and time does not permit discussing it in this presentation. Common sense dictates that we must be conscious of the dangers involved in welding operations and take proper corrective measures to prevent accidents, undue discomfort, and lost man-hours. Material must be handled safely as well as quickly. Operators should be provided with proper protective clothing, goggles, shields or whatever else they need. This should not be left entirely up to the individual. The Safety Department or Welding Foreman should assume the responsibility for seeing that the men in the shop wear the right kind of gloves, the right kind of shoes, the right kind of goggles, etc. Not only welding operators, but those working with or near them should be protected. Welding booths or areas in which welding is performed should be kept clean and well ventilated. These measures will pay dividends in prevention of accidents and increased production.

In connection with operator comfort, it is not a bad idea to set up jobs wherever possible so that the operator can be seated comfortably. This applies especially in the case of small parts which are handled on tables or benches. We all like to sit down when we are working at a desk. Welding operators also appreciate this more comfortable position whenever it is practical. The production of the man comfortably seated is likely to exceed that of one who is standing all the time.

One of the last phases upon which I will touch ties in with safety and operating factor all at the same time. This phase concerns the condition of the equipment and tools which the operators are called on to use. An operator is no better than the tools which he uses. The most highly skilled operator can turn out poor work, if his equipment is not in first-class condition. Arc-welding machines should be inspected periodically. This applies as well to oxyacetylene equipment. Torches, tips and hose should be in good shape at all times. Electrode holders, cable, ground clamps and terminals should be inspected frequently. Cleaning tools such as wire brushes and scale hammers should be in good condition. When these accessories are not in first-class condition, it will be reflected in time, quality of work, and subsequent cost.

And now, since we are on the subject of the operator, I would like to discuss perhaps the most important quality-cost factor, and one of the most neglected—operator training.

TRAINING WELDING OPERATORS

Hundreds of text books and pamphlets have been written for and about welding operators. We all know of the many excellent handbooks which are available to those who have the time—and the inclination—to read them. Our Welding Magazines have long been a source of the best and latest technical information about the various welding processes. Our A.W.S. meetings provide a wealth of very important technical data through the medium of the speakers we are privileged to hear. What then, is wrong with our training programs? Where have we failed, and why?

MATERIAL TOO TECHNICAL

For one thing, much of the published material about welding is written in such technical language the average welding operator could not understand it—*even if it was available* to him. Other data written in more interesting—easily understandable form, and very often having to do with many of the everyday problems with which he is faced, does not often enough reach him.

In some cases, advertising revenue tends to influence the circulation of trade magazines. Some operators either do not have enough buying influence to be important readers—and do not therefore get routed papers which go "upstairs"—or cannot afford to buy these books themselves. This is an unfortunate fact but true, and many operators recognize it. We have often failed to take advantage of an excellent medium for the advancement of welding—the welding operator! Certainly purchasing agents, and even job shop operators, shy away from lengthy technical books and folders because they are too busy to wade through them, and because most of them are written in language with the use of terms which are over their heads.

A.W.S. MEETINGS

We have all, on many occasions, been asked to help increase our A.W.S. membership and some sections have done a good job in this respect. Many others however, have not done well, and all could probably do much better if they considered the operators and smaller purchasers of welding equipment, when planning their program. I have been told by many of these people that they do not attend meetings, nor join the A.W.S. because they have, on so many occasions, been subjected to lengthy technical discussions on topics about which they cared nothing or did not understand. As a result the men who could probably benefit most from their association with the Society are not encouraged to do so.

Let us analyze our membership. Who are the regulars in attendance at our meetings? The welding operators? The people who buy welding electrodes and supplies? Welding supervisors? For the most part, the answers to these questions are "No." Our meetings are usually attended in full force by top brass—by plant engineers, by some top men in production and supervision and by electrode manufacturers and sales representatives. As a result these poeple are kept informed and are always in possession of the best and latest welding facts. They always get—and often read—all the finest technical publications. We are fortunate, here in our country, to have some of the best welding and metallurgical brains in the entire world. But what of our other welding people? What of the welding operators on whom must fall the responsibility for producing sound welds? On whom we must depend for the continued support of welding as an important industrial tool. On whom our very lives may depend when we consider the welded bridges, and trains; the ships and planes upon which we travel. These people, who really need the education most, rarely, if ever, get it. Thus, a multitude of essential welding facts, often considered elementary by those in authority, are not generally known to the operators.

Most welding operators have only remote knowledge of such basic welding information, even after years of good general experience. To many of these men, a change in polarity means only to push over the switch on their generators. They know nothing of the reasons for, or results of the change. Welding operators know that coated electrodes are handled more easily than the old, bare type, but they have no conception as to why this is so, or that different coatings produce varying results under similar welding conditions. Most operators, and unfortunately many supervisors and other buyers of electrodes, know little or nothing of the A.W.S. methods of electrode identification or the N.E.M.A. system of color markings. To most operators an electrode is either a "reverse polarity rod" or a "straight polarity rod"; either a "hot rod" or a "cold rod"; an "A.-C. rod" or a "D.-C. rod." In spite of the efforts of our A.W.S. and the A.S.T.M. to bring order out of the seeming chaos of the metallic arc-welding electrode situation, a state of confusion still exists among those people who should certainly know the various classifications, and understand why, and how, electrodes are so classified. Here, too, we have failed somehow to get these facts across.

PREHEATING

To most shop welders, preheating is an occasional necessary evil. Few understand the reasons for it, or the troubles which might occur because of insufficient preheat temperatures or too rapid cooling. On several occasions I have seen critical materials requiring preheat temperatures of 500 to 600° F. endangered by well-meaning operators who have decided that maybe 200 or 300° F. looked or felt hot enough. Thousands of sorely needed operators were trained during the last war to do an important job. Considering the circumstances, and the necessity for haste, they did it very well. Most training programs taught only the art of welding. On an engineering level, welding is a science. It is now up to management—and our technical socie-

ties—to teach the science; to carry on where the emergency training left off. Most operators are anxious to do good work. By knowing the reasons for proper practices and the results of improper ones, they would be encouraged to do so. In this way welding quality would definitely be improved and welding costs naturally reduced.

QUALIFICATION TESTS

The purpose of qualification tests for operators is to determine their ability to produce sound welds on the job—not just good test plates. The A.W.S. standard qualifying tests for operators were developed as an aid in determining their ability. These tests should be considered a minimum standard rather than the ultimate, and fabricators should not hesitate to test beyond these standards when necessary to determine an operators ability to do an unusual or difficult job. The manufacturer is not relieved of his responsibility to produce quality weldments by the fact that his operators have met minimum test requirements. Nevertheless, in certain cases where operators have failed to pass standard tests, they have been allowed to remake them, as many as three or four times, until, aided by the law of averages, one has finally passed, and the operator has been considered qualified!

Certainly the fallacy of such a practice is obvious. Test plates are usually made under ideal conditions. If a supposedly competent operator fails to make a satisfactory test under such conditions, how can he possibly be expected to produce an acceptable job in production? When a test fails, it should be the duty of someone in a supervisory capacity to determine the cause of the failure. When it has been determined whether the fault was defective materials or improper technique, the operator should be told what was wrong and why, so that his mistakes, if any, will not be repeated. And then, under supervision, he should be allowed to remake the test. Because it is good "quality insurance," the outlay of time necessary to conduct such an investigation would pay dividends. The operator's test plates would take on new significance, because results would then more accurately demonstrate their ability to produce welds of like quality on the job.

NEW ELECTRODES

Since producers and fabricators have developed new types of steel for special applications, and electrode manufacturers have created new and better electrodes with which to weld them, another training problem has arisen. When a welding operator has used one type of electrode for any length of time, he naturally develops a particular aptitude for it, and a tendency to use the same technique for any new rod he is asked to employ. Since many of the newer electrodes require different methods of handling, the result is usually a poor quality weld. Very often, when several attempts to produce a satisfactory weld with a new rod have failed, the operator throws it aside and reports that it is "no damned good." When several of them have thus expresed themselves, the electrode is usually ruled out by the foreman as being unsuitable. As a result, an electrode type, which had it been properly used, would have given best results, is discarded in favor of another, possibly inferior, with which the operator is more familiar. Some rods have been designed especially for their usability characteristics rather than for quality of deposit. That is usually perfectly satisfactory as far as the operator is concerned, but when closer inspection is required, or when cracking or porosity occurs, or tensile properties are not adequate, or the welds do not in other ways meet certain specifications, it is a very difficult job to convince the operator that another rod should have been used. Because the usability characteristics pleased him, he is sure the electrode must be O. K. Many welding shops use certain electrode types because the "prima donnas" among their operators insist on them, and either refuse to use any other, or deliberately turn out poor quality welds if forced to do so. In other shops certain electrode types are used because the foreman or supervisor has had some previous experience with a particular type and likes it. The fact that it may not be the best for his applications has no bearing on the matter. I know of a fairly large eastern shipyard where an E6013 type electrode is used exclusively for ship repairs, because the welding foreman formerly worked in a sheet metal shop where he learned to use that particular rod. Since it is a basic rule that this type of electrode should never be used on dirty or galvanized material—and most of the material in a ship repair yard is in that condition—it is easy to see how serious defects could occur under these conditions.

It is unfair to the welding operator to hand him a bundle of rods of a type he has never used, and expect him to produce satisfactory welds. He should first be instructed in the proper technique to follow. He should be told what current settings, approximately, are to be used, and what polarity is recommended; whether to maintain a long arc or a short arc; whether to whip or to weave. He should understand why that particular electrode is being utilized, and what welding characteristics, good and bad, to expect from it. Thus equipped he goes to his job in a proper frame of mind. Electrode manufacturers and distributors could promote good will, and better welding quality by more frequent visits from sales representatives qualified to demonstrate the usability of their electrodes. Many shops which do not have research facilities, or personnel capable of making the necessary investigations would welcome such a service.

WELDING CURRENT

Many welding operators do not understand the importance of proper current values in regard to weld quality. This fact is especially serious in shops where certain production incentive bonus plans are in effect. By using excessively high currents the operator is able

to earn higher bonus payments. He does not realize that serious defects are apt to occur under these conditions, as in the case of stainless steel types. On the other hand, certain electrodes are used to best advantage at higher amperage. The so-called "hot rods," the 6020-30 and 7020-30 classes, often cause trouble because not enough heat is used. These, the 6013, the 4-6 Cr and the recently developed low-hydrogen electrodes produce best results with somewhat higher than usual current settings. In many shops, however, even when the machines are set, the operators cannot be sure of the amperage they are getting. One shop checked and found all machines off from 20 to 60 amp. Machines should be periodically checked with some type of portable ammeters and properly set. In all cases operators should be informed of the manufacturer's recommended current settings, and told that these were suggested because of consistently good results obtained during considerable research experience. Of course, slight variations in amperage do not usually make too much difference. Current values may differ with certain conditions, depending quite often on the operator's ability, joint preparation and type and thickness of material. Heavy sections of metal will usually absorb more heat than thin sections. Poorly fitted joints require lower heats than well fitted joints. However, for best quality deposits, with proper fusion and good appearance, suggested values are usually best suited for most applications. Proper knowledge on the part of the operator concerning the effects of extreme variations in current values can do much toward eliminating such ordinary defects as rough looking welds, excessive spatter, improper or incomplete slag coverage, trapped gases and slag and poor fusion at side walls. These things, too, tend to increase welding costs.

CLEANING

Another possible cause of poor weld quality is the tendency on the part of some operators to minimize the importance of proper and thorough cleaning. In multiple pass welding this lack of cleaning very often causes porosity, slag inclusions and crater cracking. With single beads, cover layers and fillets, appearance suffers. All electrode manufacturers recommend that cleaning be thorough, yet operators in many shops still follow the old procedure of starting new electrodes in the slag-filled crater of the preceding one. Halfway measures are not enough where quality workmanship is desired. The expenditure of a few seconds to properly chip the slag from a crater, or some heavy particles of spatter from a side wall, should not be permitted to necessitate costly repairs or to jeopardize the strength of the joint in service. It is the duty of a good supervisor to impress this fact on his operators.

ARC LENGTH

Arc length, too, is a good topic for discussion. It is surprising how few welding operators know the correlation between arc length and amperes and volts. It is important that they know the results of extreme variations in arc conditions because these conditions have a direct bearing on depth of penetration, size and contour of deposit and appearance of beads. A good operator should be able to distinguish between proper and improper arc characteristics by sound, by slag performance, by type and quantity of spatter and by weld appearance.

CHOOSING THE RIGHT ELECTRODE

Because there are so many factors which determine which electrode is right for a particular job, we will only touch on a few of the highlights here. From the operator's standpoint, the choice of the right rod depends on its ease of striking and maintaining the arc in all welding positions, concentricity of coating, amount of irritating smoke or fumes and ease of slag and spatter removal. Of course the engineer or fabricator must choose from other more important angles. He must consider the chemistry of the material he is to weld, the position in which it will have to be welded, the service to which it will be subjected and the type of current which is available. Here, too, a dangerous practice should be mentioned. Purchasing haphazardly large supplies of surplus wire does not tend to improve welding quality, even though the initial cost is lower.

Selection of the proper electrode size is primarily a common sense function. Not only is it faster to use a larger electrode where the work warrants it, but also much cheaper. Less time is required by the operator to change electrodes, to restrike his arc and to clean out craters with a $^{3}/_{16}$ electrode than with a $^{5}/_{32}$. Based on actual studies, this difference results in over 40% savings in electrode changes per pound of metal deposited. In making an ordinary horizontal fillet, the change from a $^{3}/_{16}$ to a $^{1}/_{4}$ electrode results in a 50% increase in the deposition rate.

Going back to the operators again, I have found that one of the major gripes among shop welders is that they are not usually given an opportunity to learn the results of tests they have made, or jobs completed. In shops where this condition exists, management loses an excellent opportunity to get high quality workmanship. When an operator completes a piece of work, in test or production, he should be told as promptly as is practicable, the result of his effort. If possible, he should see X-ray film of his job, and be shown what defects may be apparent. If physical results are obtained he should be given an opportunity to see the specimens, and their significance explained to him. It then becomes a game in which he is anxious to excell. It produces an opportunity to discuss with him the reasons for any possible defects and a means toward suggesting ways to eliminate them. In addition, it is a good opportunity to give him a "pat on the back" if the job warrants it. Many operators, who were normally hard to convince, have been diplomatically trained by these methods. To get quality work, at lower cost, we must all realize

that fixing the fault is better than fixing the blame—and it is cheaper, too.

SUMMARY

In conclusion, let me leave you with these thoughts! Unless welding operators clearly understand the elements which go into producing good quality welds, they cannot consistently do so. Because shop foremen and engineers usually have more time for research, and are more easily able to learn the newest and best methods, they should give their operators the benefit of the knowledge they obtain. Our various A.W.S. sections should start intensive educational campaigns aimed at the operators, the small job shop owners, and even purchasing agents who might buy welding supplies. Programs should include as many as possible of the every day problems with which these people are faced, and concrete suggestions, on an instructive basis, as to how they can be solved. Large welding shops must, and small jobbing shops should have available sufficient research and testing facilities to learn at first hand what each different type and make of electrode can and will do, and how best to do it. Competent supervisory personnel should be trained to explain their findings to the welding operators. And, plain, simple pamphlets explaining the basic fundamentals of welding and the whys and wherefores of electrode classifications, and written in the language of the average layman, should be widely distributed where they will do the most good. To welding operators, job shop operators, supervisors and last but maybe most important to those buyers and users of welding equipment, supplies and accessories to whom many of these basic fundamentals of better welding at lower cost are still mysterious problems.

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Variables in Cross-Wire Welding of Dissimilar Metals

Cross-wire welding on filament structures for various types of electrical tubes involves many variables and difficulties both as to materials, techniques and equipment. Correlations are developed among these variables

by I. S. Goodman

Abstract

With the current expansion of radar, television, therapeutic and industrial lighting and similar electrical and electronic industries, the quality of cross-wire welds incorporated into the filament structures of their products becomes more important. Many firms utilize equipment which is obsolete in the light of present welding knowledge; many of the problems in making these welds are not clearly understood.

Most of the variables, in cross-wire resistance welding nickel, iron, molybdenum and tungsten wires to each other in various sizes, are discussed from the viewpoints of equipment supplier, equipment user and product manufactured. Among the joint variables are strength, conductivity, rotation, intergranular corrosion, walk-out, noise, vapor pressure and ease of welding. Equipment variables include timers, electrode materials, welder heads and transformers. Correlations are developed among these variables that will result in welds having desired properties.

IN THIS increasingly mechanized civilization, more and more of our daily life, as well as industrial progress, is dependent upon units containing lamps, tubes, photo-electric cells or similar components which operate upon or discharge electrical energy, heat, light or sound. The heart of most of these devices is a refractory metal filament, usually tungsten, ranging in diameter from $^1/_{16}$ in. to the fineness of a human hair. The failure of this filament, will render the entire unit inoperative which may mean no more than the temporary discomfort of missing a ball game on a home TV set, or the more serious inability to operate a radar set at some critical moment. Therefore, it behooves us to discuss the methods whereby these filaments and their supporting and associated metallic structures are joined.

There are many metals and many metal-joining methods used in fabricating these devices but it is the intention of this paper to confine itself to the most commonly used metals; tungsten, molybdenum, nickel, iron and nickel-iron alloys. Likewise, there are welds between sheets, wires and sheets and wires to each other; in the main, this paper will be confined to resistance welding of crossed wires to each other in diameters of $^1/_{16}$ in. and less. It will be found, however, that discussion and conclusions within these limits, can be applied to a much broader range of sizes, materials and shapes.

All filament-containing devices have a finite rated life and most filament failures after this rated period occur from natural causes generally unrelated to joining, but many premature failures can be traced to some basic fault in the design or production of the welded joints.

It is further regrettable that, in the sudden spurt generated by the television industry particularly, many of these welds are being made, especially amongst the smaller producers, with equipment that is obsolete in terms of current welding metallurgy. Some of this is due to the fact that, although the larger resistance welding manufacturers have been very quick to realize the value of low-inertia, high efficiency, welder heads in the higher kva ratings, they have not been as progressive in the bench-welder field. Fortunately, there is a good choice available of accurate resistance welding timers. Some of the fault may also be attributed to insufficient (and frequently incorrect) published information and data on the problems of cross-wire welding refractory metals and nickel alloys to themselves and each other in small gages. Among the more important published papers are those of Kiefer,[1] Freedman,[2] Jones,[3] and Gillette.[4]

The main purpose of this paper is to attempt to rectify this deficiency to some small extent and to encourage further investigation in this field. We are concerned with three basically different kinds of welds; ferrous metals to each other; refractories to each other; and ferrous metals to refractory metals. The balance of this paper may be considered as in two parts; the first discusses the variables concerned both in production and end use of cross-wire welds of these three types;

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Fig. 1 Typical prefocus lamp

the second presents factual data and some conclusions and theories for your consideration.

JOINT STRENGTH

In most welding, the strength of the joint is of paramount consideration because the joint may support a considerable mass or be continuously subject to compressive or tensile forces of some magnitude. Such is generally not the case with filaments or filament support structures which sustain only their own small weight. Thus tensile strength is unimportant per se, except where in it can be correlated to other desired properties which, as we shall see, is the case.

A more important property is ductility since many of these filaments operate intermittently or continuously at temperatures of 2500° C. or higher. Under such burning or cycling, a complex pattern of forces are applied to the assembly due to contraction and expansion, a condition that is aggravated in the dissimilar metal joint. The effects of these forces will be discussed shortly.

Some electronic devices are also subject to short but vigorous shocks, occasionally equivalent to a continuous statically applied force of several hundred G's upon the filament structure.

CONDUCTIVITY

Most of the joints to which we have reference are electrical conductors, enclosed in air or more often in a vacuum or a gaseous atmosphere of greater or less than atmospheric pressure. This is another feature that differentiates these joints from those of a cross-wire welded window screen or similar objects.

With the filament serving as a source of energy, it is desired to make the filament as efficient as possible, and it is important to eliminate all wasteful resistivities other than that of the filament. The main sources of such resistivities are the welds, since the filament supports are purposefully chosen of large diameter to reduce their resistance. While it might appear that the minimum resistivity would occur with maximum surface contact between the two wires (i.e.; 100% setdown), such a weld or one very close to it, is not structurally practical when the wires are of similar diameter. Furthermore, we are generally dealing with two dissimilar metals (e.g., tungsten to nickel) which makes the problem very much more complex, introducing factors such as the resistivities of the alloys of the two metals, different rates of oxidation, melting points, etc.

ROTATION

In some devices the positioning of the filament is not too important; in other devices where the filament output must be accurately focused, the precise positioning is of prime importance as is the maintenance of this position. Examples of devices requiring accurate focusing are motion picture projection lamps, automobile sealed beam lamps, beamed power triode and tetrode tubes, etc. Generally, limits are prescribed for the motion of these filaments with respect to a given axis during its rated life but, dependent upon the means and skill with which the filament is attached to its support, a gradual rotation will ensue leading to the weakening of the joint concurrent with cycles of expansion and contraction between two dissimilar materials during successive burning and off periods. This progressive displacement is illustrated in Figs. 1–5. Figure 1 pictures one type of lamp requiring proper focusing. The accuracy with which the horizontal and vertical alignment are maintained is illustrated in Figs. 2 and 3. Figures 4 and 5, of the same filaments above after a period of burning, indicate the rotational displacements that may occur in both planes under certain welding conditions.

Fig. 2 Horizontal alignment (before burning)

Fig. 3 Vertical alignment (before burning)

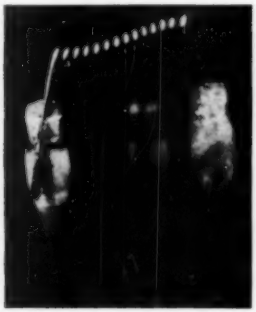

Fig. 4 Horizontal alignment (after burning)

Fig. 5 Vertical alignment (after burning)

Fig. 6 Arc-out

Fig. 7 Typical walk-out (side view)

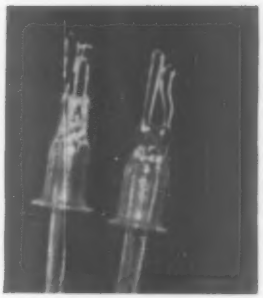

Fig. 8 Same lamp, hook and cross-wire designs

Fig. 9 Typical walk-out (front view)

APPEARANCE OF WELDS

The surface appearance of welds with which we are concerned is of virtually no consequence except in so far as it may be indicative of poor quality or lead to excessive welder maintenance.

WALK-OUT

While the joint is undergoing disturbance, as long as the current path is continuous, the device will continue to function, although probably not at maximum efficiency. However, when the motion of the filament proceeds far enough, one of two effects may occur, either of which causes failure of the part. The rotation may proceed far enough during a burning period to cause several turns of the filament barrel to touch and short; this reduction in resistivity causes a surge of current through the coil which burns out a portion leaving an open circuit as illustrated in Fig. 6. Quite often, however, the joint will loosen up sufficiently so that small jars in vibrations during a period when the device is not burning will permit the filament to spring from its support producing an open circuit and the inability of the device to relight (Figs. 7 and 9): such a movement is called a filament "walk-out."

CLAMPING AND NOISE

In order to prevent such rotation and walk-out, the joint is sometimes redesigned from the open weld construction to the closed hook construction (Fig. 8). The closed hook presents a more complex welding problem although it will eliminate premature failure due to rotation or walk-out. This problem arises from the tendency of the closed larger diameter hook to short much of the welding current through itself and from the tendency for three superimposed wires to scissor (Fig. 10) giving rise to poor joints and a higher welder maintenance due to arcing during the scissoring period. Nevertheless, many cross-wire welds are made with hooks.

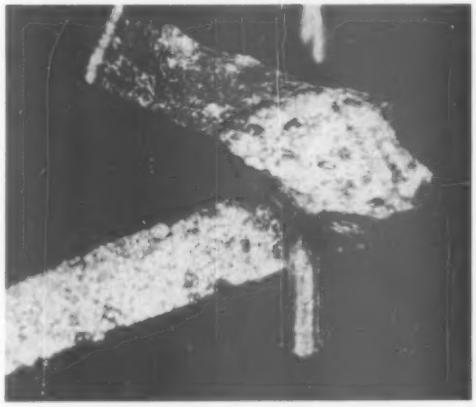

Fig. 10 Scissored weld

Where current requirements and the applied voltage during operation are low, a mechanically closed hook (clamp) is frequently acceptable without resorting to welding. If these clamps are improperly made, the filament may loosen within the hook, causing an arc-out, but, more frequent, the resultant free movement of the filament within the clamp permits it to vibrate at har-

Fig. 11 Noise tester

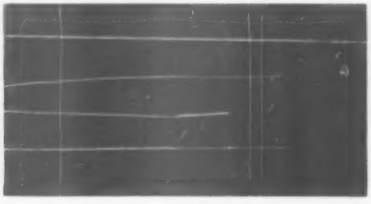

Fig. 12 Butt welded wire assemblies

Fig. 13 Bump tester

monic frequencies which appear as low amplitude radio, television, or similar interference within a limited area around the device. This vibration may be detected with a noise tester similar to the one in Fig. 11; in this device a high-frequency current is passed through the filament and filament vibrations induced by the operator's tapping are audibly amplified.

Thus in designing a filament mount, one can use a mechanical clamp, a simple cross-wire weld, or a hook weld, the choice being dictated by the particular application.

The filament support structures, grid structures, etc. which operate at very much lower temperatures are generally joined by cross-wire welding or butt welding, the choice being dictated by the size of wire and production rate required. Where the sizes are small and the production rate very high, the leads are frequently butt (or percussive) welded (Fig. 12); a subject which deserves further investigation on its own and is outside the scope of this paper.

FRAGILITY

In welding nonrefractory metals, we are seldom concerned with fragility but such is not the case when welding refractory metals to each other or to other metals. Except for small amounts of cast molybdenum, all tungsten and molybdenum metal is prepared by powder metallurgy methods; the pure metallic powders are reduced from oxides in a hydrogen atmosphere, pressed into ingots of various sizes and sintered at prescribed temperatures to provide molecular adhesion. At this stage, prior to working, the metals consist of large equiaxed grains, quite brittle with very low tensile strength. By a process of successive hot and cold working operations, the ingot is reduced to wire or sheet with a remarkable increase in tensile strength and ductility. During this working process the grains become fibrous

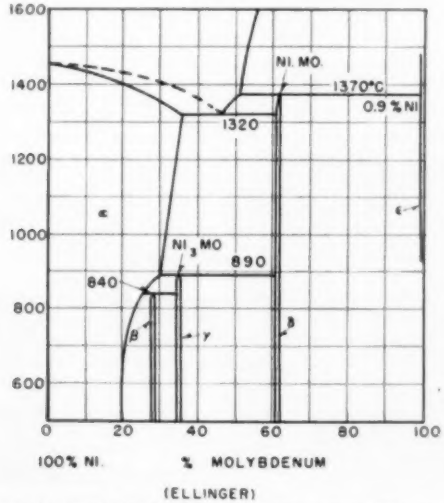

Fig. 14 Nickel-molybdenum binary system (Ellinger)

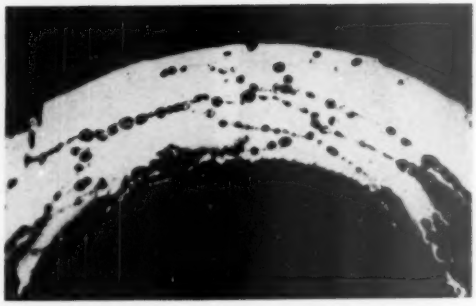

Fig. 15 "Water cycle" corroded tungsten

and elongated (Figs. 30 and 31). When the cold worked metal is reheated above 800° C. for molybdenum or 1000° C. for tungsten, the metal recrystallizes to its equiaxed-grained brittle state, the extent of recrystallization being a time, temperature and work function as it is with other metals. Accordingly, in making any molybdenum or tungsten weld we will encounter first stress relief and then more or less recrystallization and consequent brittleness. This brittleness is usually referred to in terms of the weld's fragility and is one of the prime causes of premature filament failure. To determine the extent of fragility we may employ one of the usual tensile testers or, for a better picture of shock resistance independent of tensile strength, we may employ a "bump" tester (Fig. 13). This device is a loaded lever arm with the filament under test mounted at the moving end and dropped against a pad: the load and distance of travel are adjustable.

When welding tungsten or molybdenum to nonrefractories, recrystallization can be avoided, but alloying becomes a problem. Bonds between the refractory metals and the nonferrous metals are inherently of low tensile strength due to the immiscibility of these metals in each other. Bonds between refractory metals and the ferrous metals are complicated by the formation of complex binary alloys which may have high tensile strengths but are brittle. Typical of these alloy systems

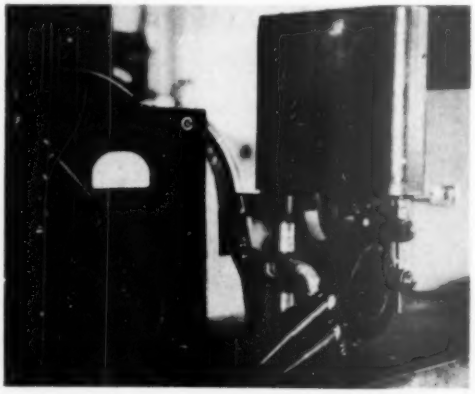

Fig. 16 Welder setup

is that of nickel-molybdenum[5] (Fig. 14), two metals frequently welded together, which well illustrates the alloy structures which may be expected in such bonds. Previous authors have tended to ascribe the brittleness of nickel-moly and nickel-tungsten welds to recrystallization; however, many metallurgical studies have established high diffusion rates of the refractories into the ferrous metals at temperatures well below the ferrous melting point, as low as 800° C. for molybdenum into nickel. The author will demonstrate later that this is a greater deterrent to strong, ductile refractory-ferrous welds than is recrystallization.

Some of the solution to these brittle welds can be found in adequate accurate control of welding time.

WELD IMPURITIES

The welding process may introduce undesirable impurities. One of these is metallic oxide adjacent to the weld. Presence of excessive oxide will accelerate "water cycle" corrosion. The mechanism of this corrosion is as follows:

Some hydrogen is always present in these sealed-off devices either as an atmospheric impurity or in the parts themselves as absorbed gas. In fact, many of the parts are baked in hydrogen before assembly in order to replace heavier absorbed gas with lighter, and more easily disposed of, hydrogen and to remove metal-fabricating oxides. After the tube or lamp has been made and is in operation, this hydrogen reduces surface and intergranular oxide that may be present on the parts, forming water vapor and freeing metallic atoms which deposit on cooler portions of the device. Almost immediately, the water vapor molecule decomposes in the intense heat reforming a new oxide molecular and free hydrogen and the process reinitiates. This process may produce premature failure of the tungsten filament through intergranular corrosion and reduction of cross-section (Fig. 15). Oxide formation during welding can be avoided by judicious choice of welding time or by the use of a neutral or reducing atmosphere around the weld.

Another source of undesirable impurities may be the welding electrodes themselves. If the electrodes be copper or copper alloy, electrode pick-up may be dangerous adjacent to or on the filament but not as critical on the filament support. Although copper is not considered as a high vapor pressure metal, it can act so at the 2500° C. operation temperature of the filament. Copper pick-up may be vaporized during burning periods and be transferred to a glass outer bulb. On many glass enclosed devices this may be insignificant but in the X-ray tube, for instance, such deposition on the "window" may seriously reduce X-ray transmission. This occurrence may be minimized by using tungsten or molybdenum welding electrodes.

Fig. 17 Test weld design

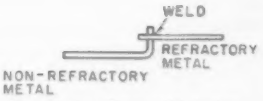

Fig. 17 A. Test weld design

WELDING TIMERS AND WELDERS

Although the application of various welding timers to specific materials being welded will be described later, a few general words now will not be amiss. Four types of timers are considered: non-synchronous timers, synchronous timers, half-cycle timers and condenser-discharge timers.

When welding refractory metals to each other, it will be shown that there is a significant gain to be made by the use of one cycle and shorter times in preference to 3 cycle or longer times. For this field we may use a one cycle synchronous timer, a half-cycle timer or a condenser-discharge timer The writer's personal experience, with one exception noted below, is all in favor of phase-shifted half-cycle. For its size, the commercially available half-cycle timers have a greater range of capacity, speaking of wattage available per weld, than most commercially available bench condensor discharge units; they are less resistance sensitive; they actually give shorter weld times (with phase-shifting, the author has oscilloscope checked them at times from $^1/_2$ cycle ($^1/_{120}$ second) to $^1/_6$ cycle ($^1/_{360}$ second) whereas similar oscilloscope checks on commercial condensor-discharge units gave welding times of $^1/_{100}$ second up to $^1/_{25}$ second; they have a shorter reset time than other timers); they do not require the high welding transformer primary insulation that is common with condensor units. The main advantages found with condensor-discharge timers are their consistency for very

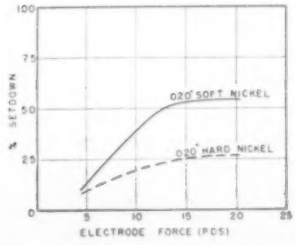

Fig. 18 Setdown vs. electrode force, no weld current

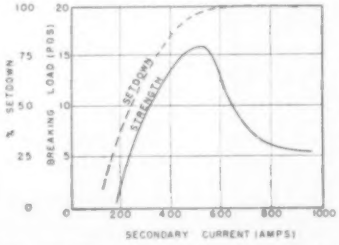

Fig. 19 Strength and setdown 0.020-in. cross-wire hard nickel, 1 cycle, 8 lb. force

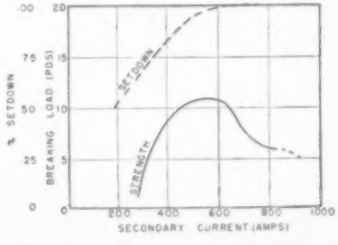

Fig. 20 Strength and setdown 0.020-in. cross-wire soft nickel, 1 cycle, 8 lb. force

light welds (involving wires and sheets of less than 0.005-in. each) where the low power requirement cannot be conveniently handled by commercially available $^1/_2$ cycle units without excessive, dissipative resistance loading and applications where a more balanced line demand is required (although this argument can hardly be held valid where weld requirements are only 200–1000 watts as is true of most of the welds discussed herein). There is also something to be said for the use of synchronous one-cycle timing in that such timers can be adopted to any welding transformer: both $^1/_2$ cycle and condensor-discharge timers tend to saturate the core of ordinary welding transformers due to the timers' unidirectional current output and render such transformers inefficient; for maximum efficiency, unidirectional timers should be provided with welding transformers having suitable air gaps in the core to prevent saturation.

For welding all but the finest gage iron or nickel metal wires to each other, the use of welding times less than 3 cycles is not significant in the end product when welding. The advantages of shorter welding times are in lack of oxidation, lower power consumption, lower maintenance, etc. In this field the choice of synchronous over nonsynchronous timers is dependent upon the consistency that is desired and in the possibility of applying phase-shifting to the synchronous units.

In welding refractory metals to the ferrous metals, it will be shown that the choice of longer or shorter welding times is not clear-cut, of which more anon.

In attempting to use welding times of one cycle or less, a low-inertia welding head may be necessary. A short welding timer may in fact be detrimental when coupled to a high-inertia head. For example, in cross-wire welding two 0.050-in. nickel wires the resultant over-all thickness may be 0.065 in.; there has been a reduction in thickness of 0.035 in., which distance the welding head must be capable of traversing in $^1/_{60}$ sec. (for a one cycle weld) while maintaining a positive forging pressure on the work. It has been our experience that some welding heads under the above circumstances will show more arcing and pitting of the electrodes at short times than at longer times. In this respect the recent production of low-inertia welders by several equipment suppliers is to be commended but a thorough investigation of the relative merits of low-inertia, spring, air and cam-operated bench welders by the larger resistance welding equipment manufacturers is indicated.

The author appreciates that this equipment question is one to provoke controversy, but does not feel conscientiously able to refrain from comment, although he restates that the views are born of his own experiences.

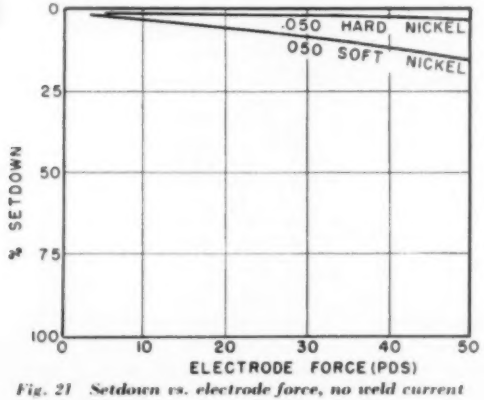

Fig. 21 Setdown vs. electrode force, no weld current

EQUIPMENT USED

Welder Heads

Some comment has already been made concerning welder heads. While we ourselves are gradually shifting to air-operated bench welders, there are still very few of these in use at present. It seemed desirable rather to conduct these tests with a good relatively low-inertia spring-loaded head of commercial manufacture. Our production has indicated that the welding head in Fig. 16 is satisfactory in this respect. It is adjustable for electrode forces of 0–50 lb. is sturdily built for minimum circuit losses, and applies its force vertically thereby eliminating the "rolling" of the weld common to rocker-arm type welders. The electrode forces used for specific test welds were measured both with a spring type balance and a General Electric pressure gage. Two of these welders were used.

Timers

Three timers were used with the two welders above to yield a full range of welding time. All three are commercially available; the first was a synchronous 1–30 cycle unit, with two WL676 switching tubes and phase-shifted heat control operating through a $2^3/_4$ kva., 24 tap transformer; the second was a phase-shifted half-cycle timer using an "A" size ignitron for switching and operating through a 4 tap, air-gapped, 5 kva. transformer; the third unit was 50 microfared, 1500 volt condensor-discharge timer coupled to a matching transformer.

Most previous investigators have recording current

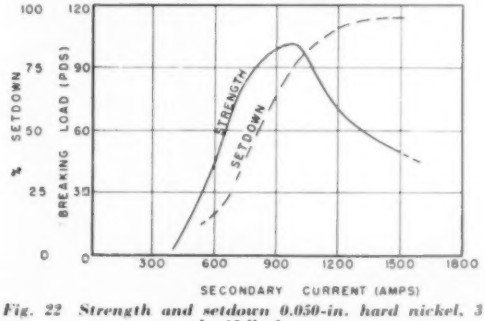

Fig. 22 Strength and setdown 0.050-in. hard nickel, 3 cycle, 15 lb. force

flow with stop-point indicators. We found these of questionable accuracy because the short time of current flow, generally used in these tests, did not permit the indicator to reach a steady state reading. Oscilloscopes are more accurate but inconvenient. For these tests, we used a current indicator (illustrated in Fig. 16) which was developed by A. B. White, formerly with the Westinghouse Research Laboratories, and is designed to measure the effective value of alternating current regardless of the weld time and compensated for the usual harmonics found in resistance welding currents. The welding currents of the condensor-discharge welds were computed on the basis of

$$W \text{ (watts per weld)} = {}^1/_2 (K)\, CV^2 \times 10^{-6}$$

The factor K is related to the efficiency of the circuit and is generally less than 1, although here assumed to be unity.

Electrodes

Electrodes used throughout were $^1/_4$ in. diameter Cupaloy (Westinghouse trade name), a Class I electrode material. Electrodes were beveled to leave a $^3/_{16}$-in. flat. Although it is common practice to vary the electrode materials to compensate for physical properties when welding dissimilar materials, this was not done, since it was felt that such a step would introduce too many variables. Another frequent procedure is to groove the electrodes so as to reduce electrode contact resistance; on high-production welding or in welding wires of very small diameter. This is not feasible due to frequent maintenance required. However, in one case, in making test welds involving more than 50% setdown between 0.060-in. molybdenum wires, grooving was found necessary because arcing was encountered due to the high-current density required for this setdown. The same electrode spacing was used for all tests.

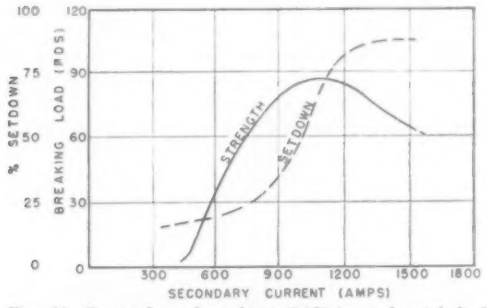

Fig. 23 Strength and setdown 0.050-in. soft nickel, 3 cycles, 15 lb. force

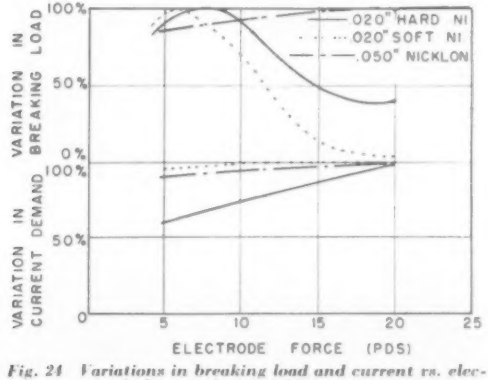

Fig. 24 Variations in breaking load and current vs. electrode force (other variables constant)

MATERIALS WELDED

In Table 1, will be found a list of materials used in these tests together with their tensile breaking load. From the work of previous investigators, it might be inferred that specific welding schedules might be established based upon percentage setdown, resistivities, etc. However, in this investigation, it was found that the worked condition of the wire, a feature previously neglected, is of major importance in discussing cross-wire welding. The tensile breaking load is being used as an indication of the state of anneal.

Table 1

Wire material	*Diameter, in.*	*Tensile breaking load, lb.*
Nickel "AH" soft	0.020	15
Nickel "AH" hard	0.020	24
Nickel "AH" soft	0.050	93
Nickel "AG" hard	0.050	170
Nicklon	0.025	23
Nicklon	0.055	141
Tungsten "S"	0.008	14
Molybdenum	0.045	169

Nickel "AH" is a pure nickel ("A") in which heavy absorbed gases have been replaced by hydrogen ("H"). Nickel "AG" is a pure nickel ("A") which has not been treated as above ("G"). Nicklon is a nickel plated pure iron material which is drawn to size after plating.

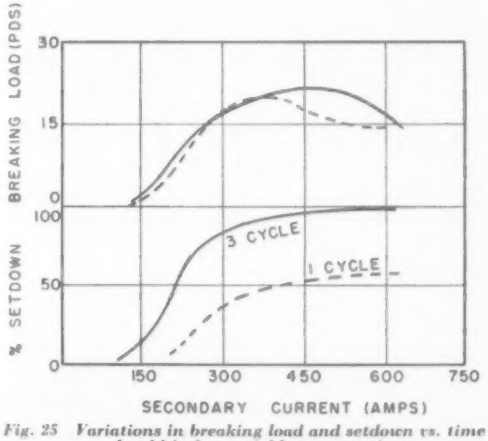

Fig. 25 Variations in breaking load and setdown vs. time of weld (other variables constant)

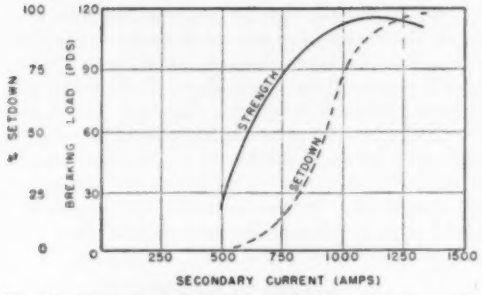

Fig. 26 Strength and setdown 0.055-in. cross-wire nicklon, 3 cycles, 20 lb. force

Tungsten "S" is a tungsten wire specially processed for filament application. The molybdenum used on these tests was regular drawn wire chemically cleaned to remove oxides for welding.

PROCEDURE

Welds between nicklon, nickel and molybdenum wires to each other were made between samples that were performed as in Fig. 17. Welds between these materials and tungsten were made as in Fig. 17 (*A*). To obtain recorded weld strengths, the welds were then pulled to breaking with one of several tensile testers available. While the value so obtained is more a measure of shear strength (but not a true shear test), we were more interested in relative rather than specific values and found that this technique suited our purpose. In early tests, the wires were positioned in the horizontal plane by fixture, but it was demonstrated that welds made by hand did not vary significantly and the fixturing was abandoned as time consuming. Shock and other tests were performed in equipment previously described. All test results reputed are based on a minimum of 5 welds per set of conditions. "Setdown" refers to the decrease in the combined diameters of the two wires as a result of welding; 0 per cent setdown being the total diameters of both wires, 100% setdown being the diameter of the one wire (the larger of the two in the case of welding dissimilar diameters).

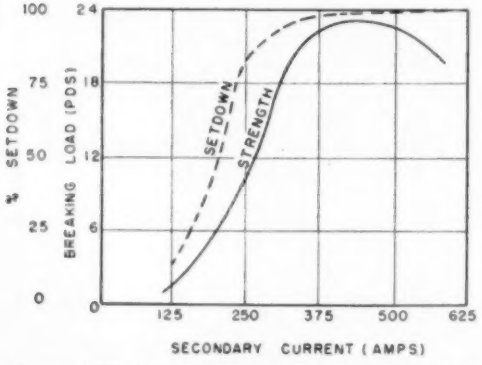

Fig. 27 Strength and setdown 0.025-in. cross-wire nicklon, 3 cycles, 8 lb. force

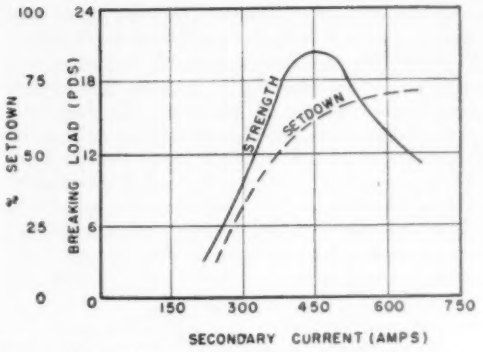

Fig. 28 Strength and setdown 0.025- to 0.055-in. nicklon, 2 cycles, 8 lb. force

EXPERIMENTAL DATA

Nickel, Iron, Nickel-Iron

We found early in our experiments, as we had previously experienced in the factory, that it is impossible to duplicate welds between the same metals without specifying their tempers. The matter of tensile strength and ductility has been largely overlooked by previous investigators. This situation is graphically illustrated in Fig. 18 which shows the reduction in thickness of two cross-wire nickel assemblies after the application of electrode force, before the passage of current. It will be seen that the percentage setdown for soft nickel is almost twice that of hard nickel of the same grade and diameter. This greater setdown increases the contact area between the wires and the wires to electrodes and decreases the respective resistivities. The net result is that, at a given electrode force, a welding current that produces a tolerable weld between hard nickel wires may fail to even tack soft nickel wires. This situation is illustrated in Figs. 19 and 20. It will be seen that the

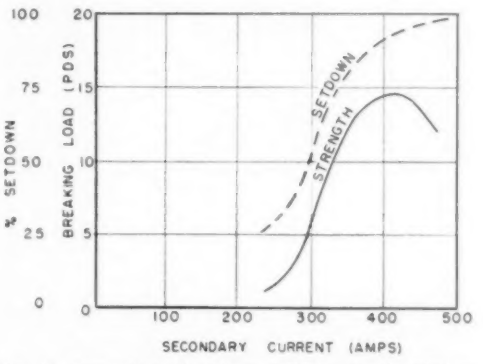

Fig. 29 Strength and setdown 0.020-in. hard nickel to 0.025-in. nicklon, 1 cycle, 8 lb. force

peak strength value as well as the strength curve is shifted toward the higher current side for the soft nickel as compared to the hard nickel, all other variables remaining constant. This is particularly aggravating, since in the industries with which we are concerned, partial annealing resulting from baking, flashing, brazing or other processes is common: thus the welding operator may be faced with welding material from a whole hard to full anneal temper.

Considering Figs. 19 and 20, it will be seen that both strength curves are similar in shape, rising steeply to a peak value at about 90% setdown, and then decreasing in strength as current is increased and setdown approaches 100%. It does not appear, as has been suggested, that 100% setdown between similar diameters is desirable for strength or electrode maintenance.

The reason for this emphasis on strength is that, these ferrous cross-wire welds are mostly used in the filament and grid or plate structures where strength may be required and among these soft materials, strength correlates closely with ductility and shock resistance.

This variation of setdown with electrode force is also a function of the diameter of the material. For instance, the variation in setdown over the range of 0–20 lb., used for the 0.020 in., does not give as pronounced an effect in 0.050-in. nickel; however, increasing the pressure to 50 lb. gives comparable results on the larger diameter (Fig. 21). The electrode force of 8 lb. used for the 0.020-in. nickel was chosen on the basis of experiments that indicated that such an electrode force was close to the optimum for this diameter, other factors held constant (Fig. 24).

A similar series of experiments were run on 0.050 in. hard and soft nickel, the results of which are depicted in Figs. 22 and 23. It will be observed that the strength curves are similar to those for the smaller diameter except that the peak strength values occur at about 75% setdown. It will be noted also that the peaks are at almost the same current for both 0.050-in. tempers, reflecting the fact that the initial difference in setdown before the passage of welding current, was much less in the heavier gage material.

Fig. 30 Tungsten ingot (1100 ×)

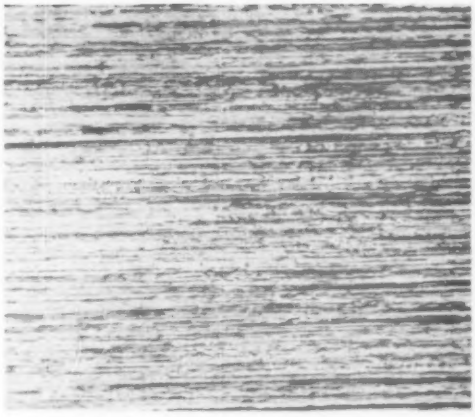

Fig. 31 Drawn tungsten wire (600 ×)

Another observation is that the ratio, of the breaking load of the weld to the breaking load of the original wire, was lower for the hard material than for the soft. This is a reflection of the partial anneal that takes place in the hard stock during welding causing it to approach the properties of the soft material.

From what has appeared above, it may be inferred that variations in electrode force, other factors remaining constant, will affect the strength of a weld. This is shown in the curves on the top half of Fig. 24. Not as obvious, but equally true, is that the current will increase, other factors constant, due to the decreased resistivity with increased pressure as shown in the lower half of Fig. 24.

It was also of interest to investigate the variation in

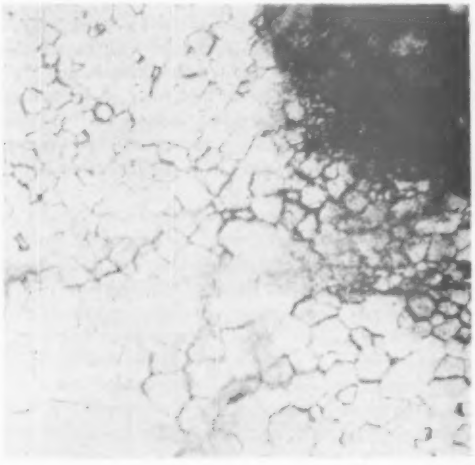

Fig. 32 Poor molybdenum-molybdenum weld (5 cycles) (150 ×)

breaking strength and setdown with welding time. These variations are graphed in Fig. 25. While the breaking strengths of 1 cycle and 3 cycle welds are comparable, the setdown of the longer time welds is greater as might be expected.

Welds between similar diameter, cross-wire, 0.055- and 0.025-in. Nicklon (nickel-plated iron) wires are very similar to the curves of nickel. Figure 26 of 0.055-in. nicklon may be compared to Fig. 22 of 0.050-in. nickel; Fig. 27 of 0.025-in. nicklon may be compared to Fig. 19 of 0.020-in. nickel.

In welding dissimilar diameters or dissimilar metals, but restricting the materials to the ferrous group, it is found that the properties of the welds are dependent upon the smaller diameter or softer wire. Figure 28 shows some test results between 0.025-in. nicklon wire welded to 0.055-in. nicklon wire. The strengths are comparable to those previously found for 0.025-in. nicklon cross-welds (Fig. 27) except that the setdown for specific breaking loads is lower and the current demand higher. This would be expected when welding the smaller wire to a larger mass than to itself.

These same comments apply to the welds between the 0.020-in. hard nickel and 0.025-in. nicklon which data is graphed in Fig. 29. These curves may be considered as hybreds of those in Figs. 19 and 27. The weld being dominated by the smaller nickel diameter but not to the same extent as in Fig. 28.

Molybdenum and Tungsten

Some of the properties of these refractory metals have already been described and illustrated (Figs. 30 and 31).

Cross-wire welds can be made between these metals at welding times of $^1/_2$ to 5 cycles. When welding molybdenum using welding times above 5 cycles, there is so much intergranular oxidation as to make the joint useless, in addition to a troublesome vaporization of molybdenum oxide which deposits on the welder, parts and adjacent areas.

Using the upper range (3–5 cycles) of the permissible zone results in welds of fair tensile strength, and good setdown but with very poor ductility and breakage above the weld. This is due to a large recrystallized area with very coarse grain structure and the frequent occurrence of intergranular cracks as illustrated in Fig. 32.

Using $^1/_2$ cycle or condensor-discharge introduces another difficulty. Because of the very high melting point and good conductivity of moly, in order to obtain much setdown with these short times, a very high-current density and high pressure are required. Under these conditions, one frequently experiences pitting of electrodes, even if grooved, and stress cracks due to rapid heating and cooling. The most consistent welds, if not the strongest are made with moderate pressures, allowing about 25% setdown, and using about a $^1/_2$ cycle weld pulse (Fig. 33). Table 2 lists experimental data on a number of 0.045-in. molybdenum-molybdenum cross-wire test welds.

Table 2—0.045 In. Molybdenum Cross-Wire Test Data (20 lb. Electrode Force)

Time	*Secondary current, amp.*	*Breaking load, grains*	*Setdown, %*
$^1/_2$ cycle	665	50– 250	6
$^1/_2$ cycle	775	150– 325	8
$^1/_2$ cycle	1420	1500–2800	20
$^1/_2$ cycle	1700	5000–7500	28
$^1/_2$ cycle	2000	2000–9000	35
3 cycle	750	3000–7000	12
3 cycle	900	1000–6000	16
5 cycle	1000	700–5500	34
Condensor-discharge	1400 V. at 50 mu	100– 600	3
Condensor-discharge	1600 V. at 50 mu	250–1350	7

Much the same conditions are found in tungsten-tungsten cross-wire welds. Such welds generally have even less ductility because more heat is required to form the weld nugget and generally more recrystallization

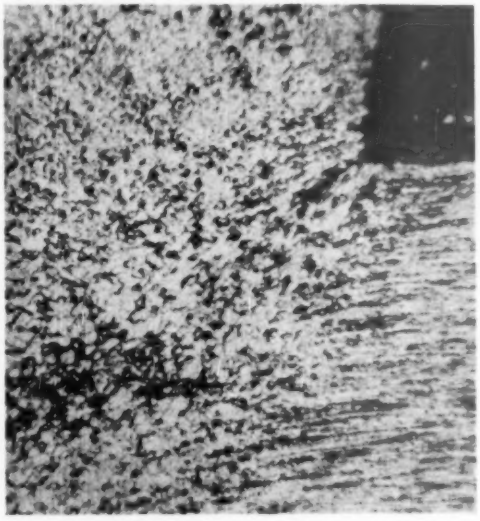

Fig. 33 Good molybdenum-molybdenum weld ($^1/_2$ cycle) (150 ×)

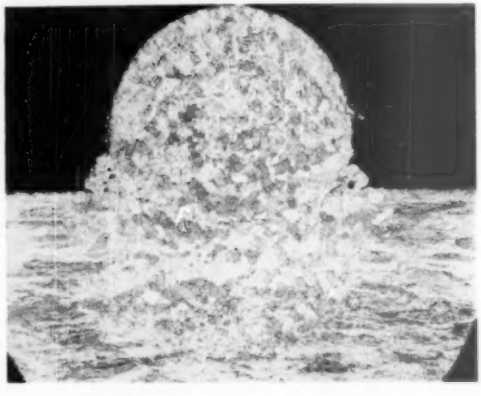

Fig. 34 Tungsten-tungsten weld (40 ×)

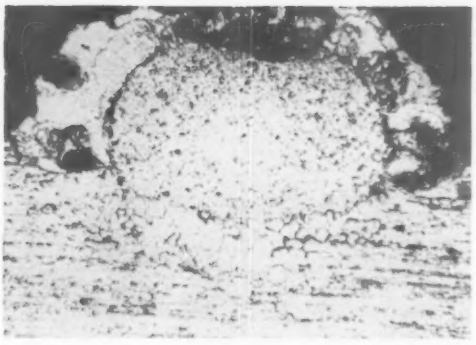

Fig. 35 Tungsten-molybdenum weld (200 ×)

sets in. Figure 34 shows an exceptionally good tungsten cross-wire weld between two 0.008-in. wires. Notable are the absence of cracks, restricted zone of recrystallization, and good grain growth across the original zone of contact; yet this weld had a shear strength of only 200 gm.

Molybdenum to tungsten welds can be made by procedures as above but are extremely variable due to recrystallization and the formation of brittle moly-tungsten binary alloy (Fig. 35).

Due to these various difficulties, welds between refractory metals are occasionally made with nickel or platinum ribbon between the faying surfaces, as a sort of brazing alloy, reducing the current demand and recrystallization of the tungsten and molybdenum, and increasing the weld strength accordingly.

Molybdenum, Tungsten to Nickel, Iron

Welds between refractory and ferrous metals are very complicated by three independent reactions:

1. We have already discussed recrystallization which occurs with the melting or excessive heating of molybdenum and tungsten. Many writers have blamed the brittleness of welds between the refractory metals and iron or nickel or this phenomenon. We have been totally unable to find any metallographic evidence of recrystallization in such welds where the diameter of the nonrefractory metal is considerably greater than the diameter of the refractory metal as is usually the case. For instance in cross-wire welding 0.008-in. tungsten to nickel of 0.020–0.060-in. diameter, no sign could be detected of grain germination, even when the weld times were increased to 20 cycles or the current increased manifold over normal: stress relief—probably yes, but recrystallization—very slight, if any.

However, in welding wires of comparable diameter, which is seldom the case in practice, recrystallization can and does occur, and precautions against brittleness must be taken as with welds between refractories.

2. The main reason that recrystallization does not occur with increased current or time is that the lower thermal and electrical conductivity, the lower melting point and the softer temper of the nonrefractory metal, quickly permits the tungsten or molybdenum to penetrate completely into the softer material which then acts as a short circuit between the welding electrodes. At the same time the molten displaced ferrous metal flows around the tungsten or moly forming a kind of clamp which contributes greatly to the strength of the joint.

3. As the molten lower melting metals flow about the tungsten or moly, a brittle series of binary alloys are formed which are probably the main culprits in lowering the strength of the joint. These alloys are very clearly seen in photomicrographs and have been previously referred to in Fig. 14.

We found that small changes in pressure, weld time, diameters welded, would significantly change the shape of the curves relating the strength of the joint to the welding current due to the relative independence of the three factors described above. Figures 36–38 represent some of the data but the application of these data to other conditions should be attempted with care. Figures 39–41 consist of a series of welds at $^1/_2$ cycle which illustrates these conditions.

If sufficient current is available to achieve a setdown of close to 100% with 1 cycle or less, low times are to be distinctly preferred to higher times because the lower weld times will reduce the amount of brittle alloy formed and also reduce the amount of refractory oxide thereby assuring better wetting and clamping of the refractory by the nonrefractory melt which appears to be the best criterion for a high strength weld and a low-resistivity joint.

However, fragility and walk-out after burning do not

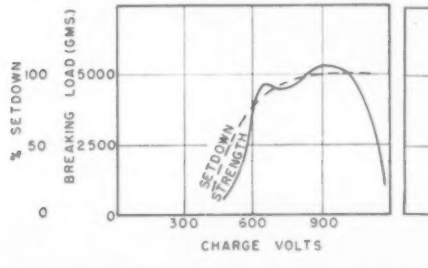

Fig. 36 Strength and setdown condenser discharge

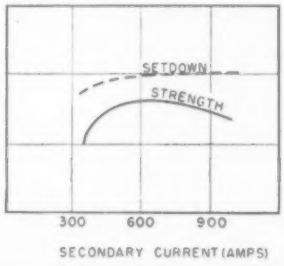

Fig. 37 Strength and setdown, 5 cycle weld, 8 lb. force

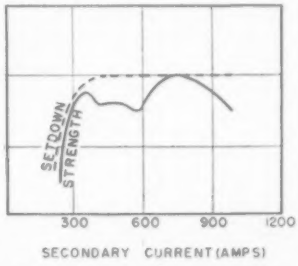

Fig. 38 Strength and setdown, $^1/_2$ cycle weld, 8 lb. force

bear the same relation to strength. Fifty test lamps each were prepared having a 0.008-in. tungsten filament cross-wire welded to 0.040-in. nickel support wires, each set of 50 being welded at $^1/_2$ cycles, 1 cycle, 5 cycles and condensor-discharge so as to approximate the same weld conditions in so far as possible. Set down varied from 80% for the $^1/_2$ cycle welds to 98% for the 5 cycle welds. Half of each test was burned intermittently so as to encourage a walk-out condition and the balance were burned continuously. The results tabulated below indicate that short times are preferable for nonfragile welds whereas longer time welds are preferable for decreased walk-outs.

Table 3

Weld time	*Continuous burning*		*Intermittent burning*	
	Fragility score	*Walk-out score*	*Fragility score*	*Walk-out score*
$^1/_2$ cycle	100	77.1	100	66.4
Condensor-discharge	100	77.4	100	62.5
1 cycle	100	83.3	87	70
5 cycles	85	87.5	60	71.4

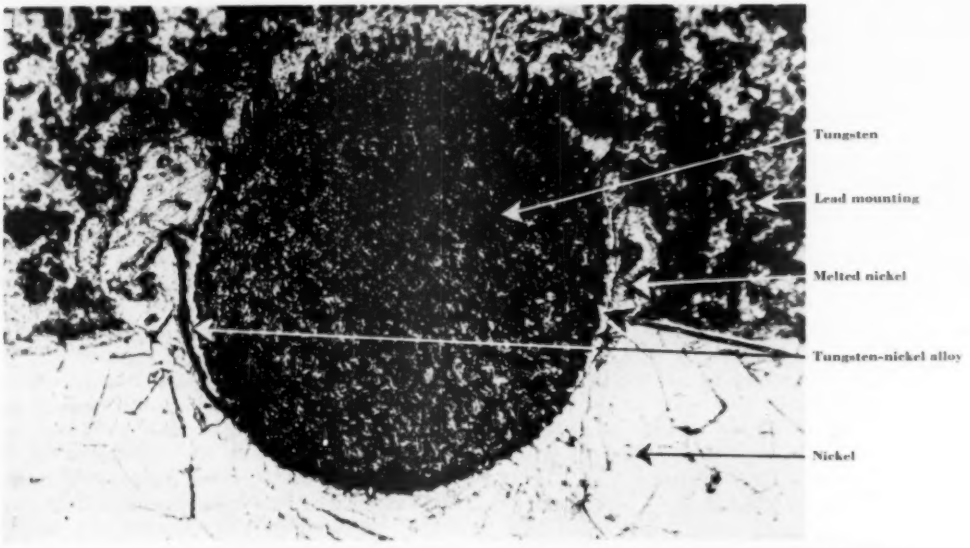

Fig. 39 Cross wire weld—0.020-in. nickel—0.008-in. tungsten, $^1/_2$ cycle, low current, low setdown (300 ×)

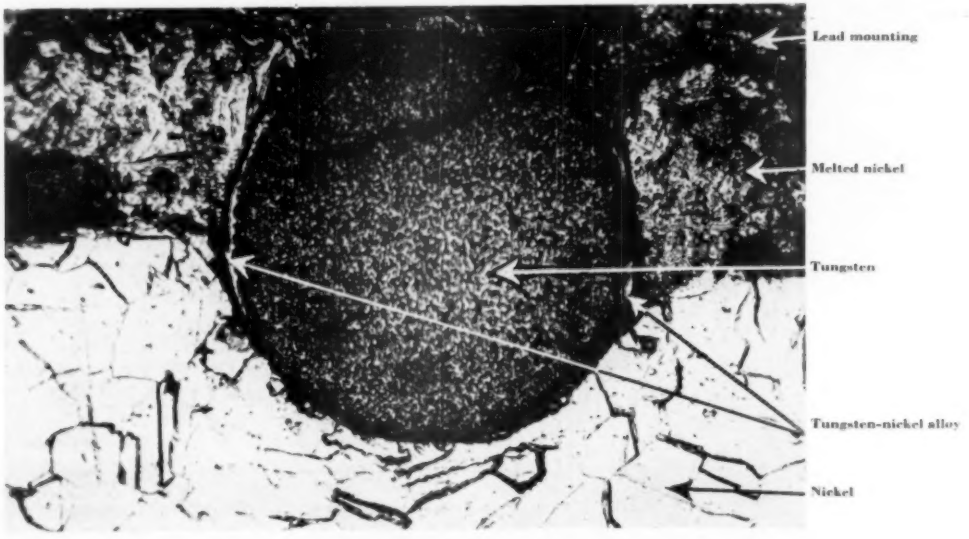

Fig. 40 Cross wire weld as Fig. 39; more current, greater setdown (300 ×)

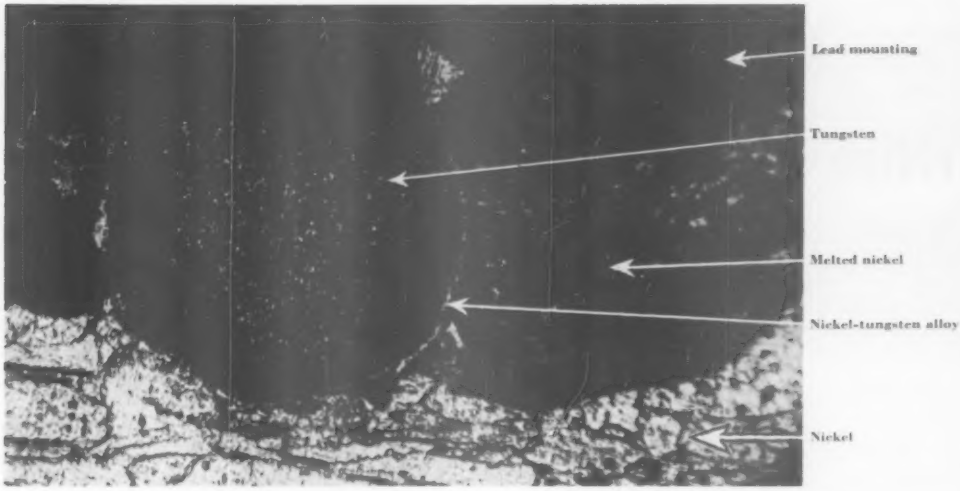

Fig. 41 Cross wire weld as per Fig. 39, optimum setdown (300 ×)

More work is indicated in this field, in which we are ourselves continuing experimentation, to establish close guides for improved welds. It is here that the low-inertia welder head offers the greatest promise of maximum setdown with minimum weld time.

CONCLUSIONS

Concerning Nickel, Iron or Nickel-Iron Cross-Wire Welds

1. Welding variables cannot be specified without regard to the temper of the material being welded.
2. The softer the material, the greater will be the current demand for a given weld strength.
3. The peak strengths occur at different setdown percentages for wires of different diameter or temper. Setdowns observed for materials tested varied from 50 to 90%.
4. Other variables remaining constant, differences in electrode force greatly affects the welds. Difference in welding times (1–3 cycles) do not significantly affect the welds.
5. The strengths of welds are limited by the tensile strengths of the original wires.
6. In welding dissimilar diameters or dissimilar metals (within the ferrous group), weld properties will be dictated by the smaller or softer of the two wires and are comparable to cross-wire welds between two of the smaller or softer wires.

Concerning Tungsten or Molybdenum Cross-Wire Welds

1. Weld properties are variable and dependent upon the amount of recrystallization and stress.
2. The most consistent welds are made with short times, at moderate pressures, with low-inertia welder heads.

Concerning Cross-Wire Welds Between Ferrous and Refractory Metals

1. Due to the concurrent effects of three independent variables, it is difficult to set precise conditions for welding.
2. Maximum strength occurs close to 100% setdown, provided that the weld has not been excessively embrittled.
3. The less the welding time, the lower the fragility for a given setdown: the greater the setdown, providing that the wetting is satisfactory, the better the resistance to "walk-out."

ACKNOWLEDGMENT

The author wishes to express his appreciation to the Metallurgical Dept. as well as the Management of the Lamp Division of the Westinghouse Electric Corp. for the time and facilities allotted to this project, to his colleagues for their valuable aid, and, in particular to Alvin A. Wisco for the preparation of specimens and photographs used in this paper.

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Welding High-Pressure, High-Temperature Piping

Some practical hints for meeting the exacting specification requirements for high-pressure, high-temperature piping

by H. J. Irrgang

DURING the past few years high-pressure, high-temperature pipe fabrication has changed almost daily in so far as pressures and temperatures are concerned. Consequently, the material used in this operation is changing just as frequently. These materials are quite varied in their constituents so the methods of fabrication and welding these materials are just as varied.

As an illustration the following are some of the tube materials commonly used today. Using the A.S.T.M. specification symbols, they are:

A-53 Grade A & B
A-106 Grade A & B
A-206 or carbon moly
A-213, A-280, A-158 and A-213 or chrome moly material and also the chrome nickel or stainless materials

All of these materials have proved their suitability for their particular requirements in service. However, this variation of materials has presented quite a problem to the piping contractor because each material may differentiate somewhat in its methods of fabrication and welding and the contractor must have on hand the equipment and experience to fabricate properly any and all these various materials and produce a product that meets with the requirements of the Codes and the customer's specifications.

Before starting fabrication on a new material the contractor must set up a procedure that will accomplish satisfactory results as required by these codes and specifications; for bending, forming and welding. In the bending and forming operations procedures are set up to control grain size, hardness, precipitation and graphitization not only during the actual fabrication but later in actual use.

In some cases where it is considered impractical to full furnace heat treat the piece of fabrication after bending, forming or welding, procedures are set up and maintained to make sure that the piece does not contain any detrimental residual strains or stresses and that the physical properties of the material are not impaired in any way. For instance, a bending procedure was laid out for 12-in. schedule 100, A.S.T.M. specifications S.A.-280, the procedure called for the pipe to be heated slowly to 1900° F. maximum and the bending operation to be completed before the temperature dropped below 1400° F., the bend is then to be removed from the table and covered with asbestos blankets and allowed to cool slowly to room temperature. The procedure was tested and the following results were realized.

CHARPY KEYHOLE IMPACT SPECIMENS

Transverse specimens—22 to 36 ft.-lb. Av. 29.5 ft.-lb.
Longitudinal specimens—26 to 36 ft.-lbs. Av. 31.6 ft.-lb.

Longitudinal 0.505-in. tensile specimens

Yield	—32,500 psi.	Elongation in 2 in.	—36%
Ultimate	—62,750 psi.	Reduction in area	—63.3%

Grain size was found to be enlarged slightly but not enough to be considered detrimental.

Welding procedures are established very much in the same way as in bending for not only is the weld required to have the same chemical and physical properties as the tubing but it must be proved that these properties are not impaired in any way by improper heat treatment after welding.

Anyone familiar with the requirements of Paragraph P-112 and Section IX of the A.S.M.E. Boiler Code, know that certain requirements must be met in so far as to the establishment and qualification of welding procedures. This, however, is not the only problem facing the fabricator when he undertakes a contract which entails the fabrication of a new material used today on high-pressure, high-temperature piping. First, his welding procedure must be sound and complete as far as preheat temperature, voltage and amperage used, type and size of electrode, number of passes for given thickness and time and temperature used in the stress-relieving cycle.

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Scheduled for presentation at the Thirty-First Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

Fig. 1 Partially completed pipe joint with convex contour

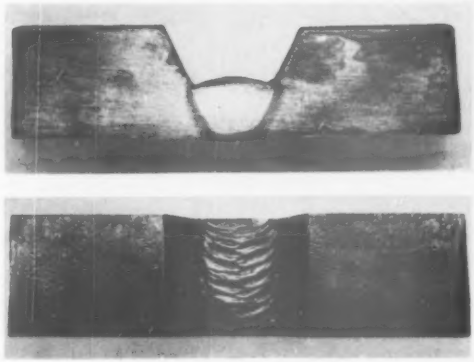


Fig. 2 Cross section of partially completed weld with convex contour

The next step to be accomplished is to qualify this procedure and at this point it should be emphasized that, no matter how particular the fabricator has been in the establishment of his procedure, he can have considerable difficulty in having his procedure qualified by the welder if he is not just as meticulous in the supervision of the operator as he was in the drawing up of his procedure.

There are many short cuts to be enjoyed by the piping fabricator if he is willing to take the time and trouble to train properly the operator in the proper technique of welding heavy wall pipe for it has been established that if certain results are obtained by following a certain procedure we are reasonably sure of attaining the same results every time this procedure is followed.

It is commonly known that one of the main causes for the failure of the operator to produce a satisfactory weld is porosity and the only way to correct this condition is to remove the slag and whatever surface defects that may appear, by chipping or grinding. This, however, can prove to be a costly operation because it not only removes material that has already been deposited but,

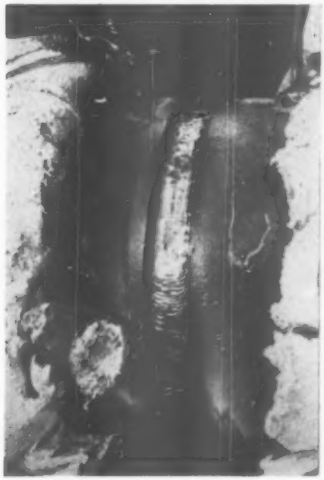


Fig. 3 Weld chipped to provide operator with a clean smooth surface for second pass

Fig. 4 Concave surface is easier to clean and undercuts eliminated

Fig. 5 Cleaning surface with a power-driven rotary wire brush

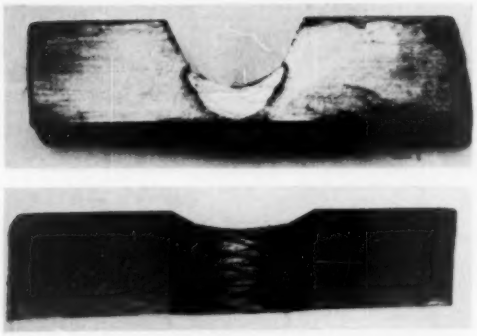


Fig. 6 Cross section of weld untouched by the chipper

it also retards the deposition time while this chipping is being done.

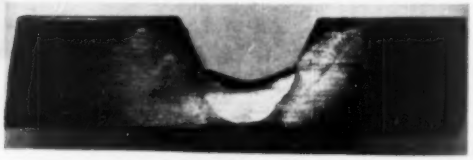
Figure 1 shows a joint partially completed. This weld has a decided convex contour on the face of the weld and there is likelihood of slag becoming entrapped at the corners of the joint and if it were not corrected, this condition would become more aggravated as the weld progressed. A cross section of this weld is shown on Fig. 2.

Figure 3 shows the amount of chipping required to provide the operator with a clean, smooth surface before proceeding with his next pass.

Figure 4 illustrates a different shape in the surface of the weld. The contour is concave in shape instead of convex, hence, it is much easier to clean as the undercuts at the side walls of the groove are practically eliminated and Fig. 5 shows how easy it is to clean completely the surface with a power-driven rotary wire brush.

Figure 6 shows a cross section of this weld untouched by the chipper and the consistency of the shape of the chamfer as the weld progresses can be noted. The only section of the joint where chipping may be required is at the start of the pass on the bottom of the joint, if the weld is made in position as shown in Figs. 7 and 8.

Figure 9 shows a completed circumferential butt weld with a thermometer connection welded adjacent to it.



Start of weld in each direction at bottom of curve

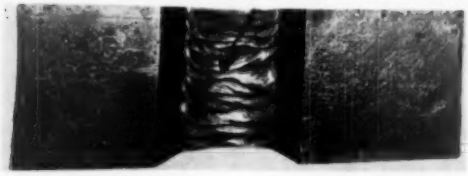


Fig. 7 Chipping only required at start of bottom pass

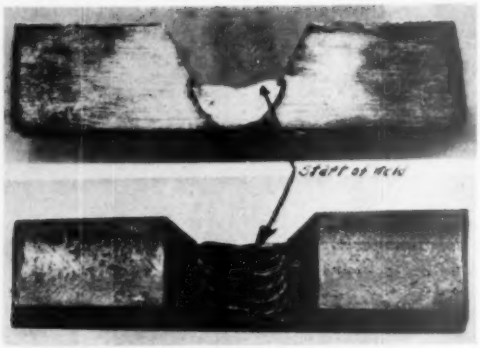


Fig. 8 Start of bottom pass requires chipping

This weld is made on 8 in. Schedule 100—Grade B material. The actual time involved on this weld was 6 hr. which included welding, cleaning and chipping. After stress relieving this weld was Gamma rayed and there were no defects found in the picture that would require their removal.

This technique in pipe welding requires a little training and practice but, when this has been accomplished, the contractor can feel that he is getting the utmost in quality at below the average cost.

It must be remembered that piping used for high pressure at high temperature is highly specialized and the cost of fabricating this pipe is considerably higher than that used in low pressure, hence the skill used in the fabrication must be of a much higher caliber. However, if the engineer is careful in his selection of the material and the fabricator is just as careful in his procedures of working these materials, these costs can be brought down

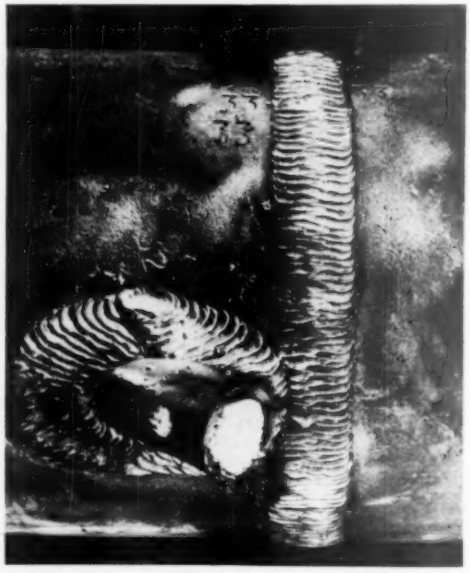


Fig. 9 Completed circumferential butt weld

considerably from their present-day prices; and if the fabricator makes certain that these procedures are followed out to the utmost and by spending a little time and money to train the mechanics who are to do this work, I feel sure that his margin of profit will be substantially equal, not to mention the feeling of security he will have after knowing he has completed a job well done.

Welding Aluminum with Inert Arc D. C.

Advantages of welding aluminum with inert-gas-shielded arc using direct current and helium gas

by John W. Mortimer

IN KEEPING with the theme of the Metal Show "High Production" welding plays a major roll. To keep high production, every type and method of welding has a place to fill.

Aluminum has been a much desired metal for its beauty as well as its strength, lightness and corrosion resistance. Aluminum, a difficult to weld metal in the past, has become an easy to weld metal with the inert-arc process. The most popular process has been the standard a.-c. welder with high-frequency superimposed. There are a.-c. welders on the market that are built with a high-voltage secondary that give excellent results and these have a starting hi-frequency circuit that cuts out automatically as soon as the arc is established. These a.-c. welders are high in cost and do not meet all welding demands that are present; such as, making several tack welds in rapid succession. The initial investment runs about three to four times the investment of standard d.-c. equipment of the same output.

The more popular type of a.-c. welding is with the standard a.-c. welding unit and the hi-frequency attachment or arc stabilizer. To weld aluminum with this combination of equipment, the hi-frequency is on all the time. The standard a.-c. welders are not built to stand this high voltage for long periods, and the transformer finally fails. The windings may be punctured or the arc stabilizer burns out. It has proved to be rather expensive to maintain this equipment under continuous service.

There has been trouble with radio interference with hi-frequency circuits. These have resulted in rulings by the F.C.C. that make it impossible to use this type of equipment under certain conditions that are usually out of the users control.

If you are handicapped by any of these disadvantages, then you will benefit by the new technique of welding with the inert-arc process. If you already have this expensive equipment, you may further your economic gains by extending your own processes without further investment.

The inert arc was put into production during World War II for welding magnesium and stainless steel. Helium was used because of its availability and low cost. Since the war, argon has been produced in quantities for inert-arc welding. The purity and moisture free argon gas proved to give better control with welding of the thin-gage metals. Heavy plate welding was only ventured into by a few, but the demand was there for higher amperage torches for the hard to weld metals. Helium is a natural for this field because it gives about a third again as much heat as argon with the same amp. setting. Today, helium is available with high purity and moisture free that makes it ideal for many welding procedures. It is possible to weld aluminum today, with equal quality to that made by the a.-c. hi-frequency circuit using argon gas shield, by using helium and d.-c. straight polarity. There are three advantages that are apparent by using d.-c. and helium; namely the low-initial cost of equipment, no possible hi-frequency interference and the lower cost per cubic foot of helium as compared to argon.

The first advantage has already been expanded, namely standard d.-c. motor generator sets costs about one-third to one-quarter the investment needed to buy the a.-c. high potential hi-frequency units for the same output rating.

The second advantage of no radio interference will be a necessary consideration for those companies affected by the F.C.C. ruling.

The third advantage of lower cost per cubic foot of gas has a universal appeal. The cost per tank of helium is roughly 74% that of argon. At this point, there are several facts to be considered. Because the atomic weight of helium is 10 times lighter than argon, it takes about 10 to 20% more helium for adequate protection to the molten metal, but because the helium-arc is hotter, about 40% more footage will be covered with the same heat. Each shop will find this relation approximately true with small variations. The over-all picture shows helium with an economic advantage of about 10 to 20%.

While aluminum has been welded with the inert arc using argon and hi-frequency, it cannot be welded with

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d.-c. and argon gas and produce a high-quality weld. Aluminum can be welded with d.-c. straight polarity inert arc when using high-purity helium. Low-purity helium will not produce good welds. The U. S. Bureau of Mines puts this high-purity helium at 99.99%. The use of this high-purity helium has opened a new control over welding that will insure "high production" in all its procedures.

The technique required to weld aluminum with d.-c. is not the same as with a.-c. and hi-frequency; the difference is in the manner the filler rod is fed. The rod must be held similar to the technique used in gas welding aluminum. The end of the rod is held continuously in the molten pool. This technique makes it very difficult to do certain types of welding; however, the stringer bead procedure has long since been accepted as being the superior type welding as compared to weaving. It is possible to do groove welds, square butt welds and fillet welds all with the stringer bead method.

The physical strength, ductility and toughness of the weld deposit are equal to, or greater than, the base material. These physical characteristics are necessary to qualify welding of aluminum plate to A.S.M.E. Code requirements. Code Case 994 states that the elongation as determined by the free-bend test shall be not less than 25%. The tensile strength shall be not less than 85% of the minimum specified tensile strength of quarter-hard or as rolled plate and not less than 95% of the minimum specified tensile strength of annealed plate. Test plates on $^1/_4$-in. thick aluminum plate show tensile strengths of 14,400 lb. per inch with 29% elongation, with 13,000 lb. per inch required. The free-bend test show 26% without any failure with 25% required. The guide bends pass without defects, showing toughness with the conbination of bending and tensile stresses. Test plates of $^1/_2$, $^3/_4$, 1, $1^1/_4$ and $1^1/_2$ in. in thickness have all proved satisfactory to the code. With plates of $^1/_2$ in. and over in thickness, groove welds were made using the stringer bead technique. Refer to Figs. 1–4 for cross-section views of welds that have been physically tested. All of these welds have been found sound and of U-68 quality.

Fillet welds can be made in the horizontal and flat positions with the same technique as used when welding butt welds. When large welds are required, the stringer-bead procedure is used. (See Figs. 3, 4 and 6.)

Cabinet welds or corner welds made with two plate edges at right angles to each other are very readily made. These welds can be made with or without filler metal, according to the method used to make the joint.

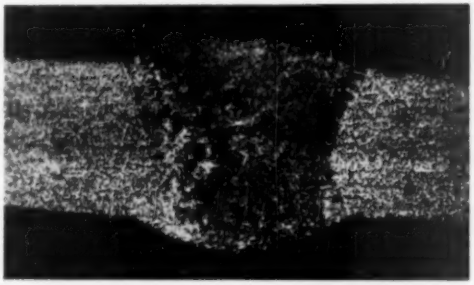

Fig. 1 Macrograph — 4 ×. $^1/_4$-in. Aluminum plate butt weld—made with square butt edges

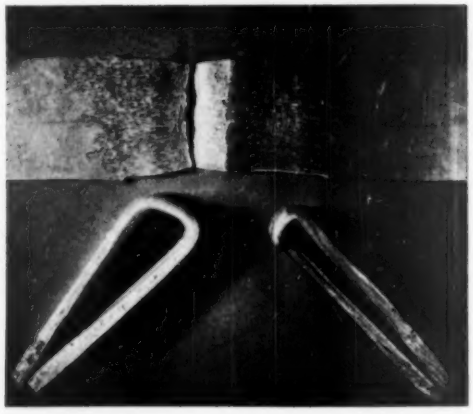

Fig. 2 $^1/_4$-in. Aluminum test bars tensile and free-bend bars

Fig. 3 Macrograph 3 ×. $^1/_2$-in. Aluminum plate butt weld—made with welding grooves on both sides of plate

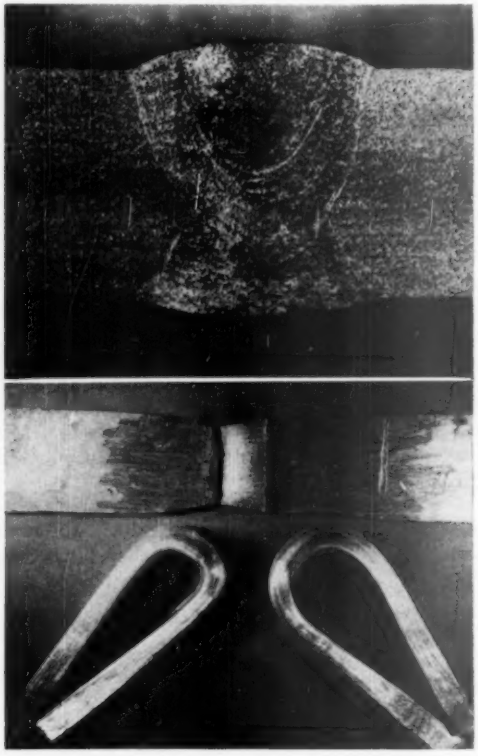

Fig. 4 $^1/_2$-in. Aluminum butt-weld tests tensile and free-bend bars

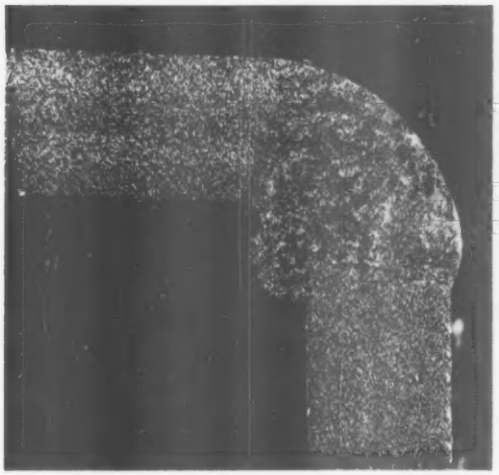

Fig. 5 Macrograph—4 ×. 1/4-in. Aluminum-plate cabinet weld

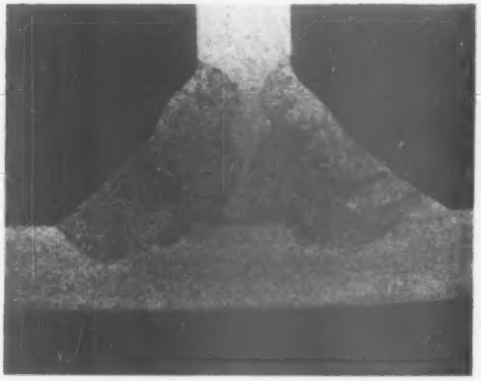

Fig. 6 1/2-in. Aluminum-plate fillets

Fig. 7 Macrograph—2 1/2 × 1/4-in. Aluminum-plate lap welded

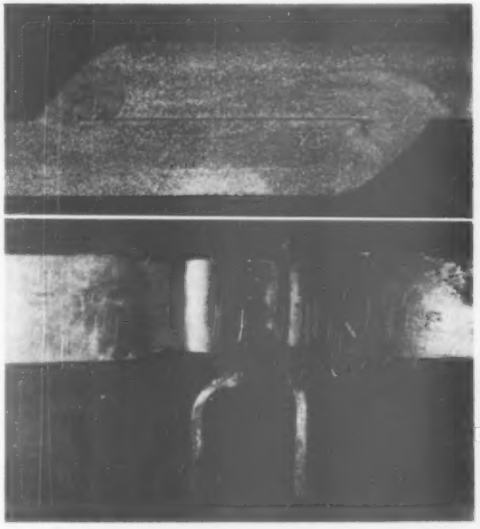

Fig. 8 1/4-in. Aluminum lap weld test bars tensile and guide bend

(See Fig. 5.) With sheet material or thin gages, upset joints make a quick and easy fit.

Lap joints welded from each side make a quick and easy fit-up; however, these joints are not as strong as butt joints. Where strength is not of prime importance, the lap joint is probably the most economical type of construction. Storage tanks of all types can be made with this joint. (See Figs. 7 and 8.).

Aluminum and aluminum alloys all weld with equal ease and are of equal quality. Alloy 2 S, 3 S and 61 S have all been welded with little loss in the plate characteristics. The big advantage in d.-c. straight-polarity welding is that the weld penetrates into the plate and the overlay is very narrow. This fact makes it ideal for alloy welding where plate dilution is of prime importance.

A few production jobs of aluminum have been built using this process. A weldment of 2 S welded with pure aluminum rod was made in record time without flux or back chipping of butt welds. The underside in all cases was only wire brushed and welded.

A large disk with a heavy rim and hub was welded with 5% silicon rod on 61 S base plate. This entire job was done without any procedure modifications.

Like all welding processes, cleanliness is next to godliness and this applies to welding aluminum with d.-c. inert arc with helium gas shield. Aluminum has an oxide film coating that must be removed from the welding plate edge as well as from the filler rod. Once this is done, the welding may proceed without flux of further preparation. The overlay has a dark oxide film along both edges which can be easily removed by light wire brushing.

The future of aluminum welding will undoubtedly be effected by this new process. The over-all economy and use of present equipment make this future bright.

Fabrication of Main-Line Road and Switcher Locomotives

Standardization and fabrication of the principal component parts as individual units prior to complete assembly have streamlined production of switcher and main-line road locomotives

by F. T. Perry

INTRODUCTION

PRESENT-day methods of fabricating Diesel-electric and electric road and switcher locomotives did not just happen overnight but are the result of years of planning and design improvements. Now, standardization plus fabrication of the principal component parts as individual units prior to complete assembly have streamlined production. Some of the problems involved in these processes are discussed here. Since the welding problems are somewhat different in the two types, they will be considered separately.

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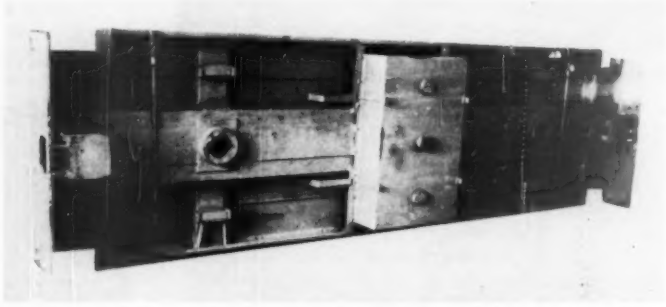

Fig. 2 Switching locomotive platform after completion of welding

WELDING OPERATIONS ON A SWITCHER LOCOMOTIVE

Industrial switcher locomotives are built in sizes ranging from 25 to 95 tons, with ratings of 150 to 660 hp. A typical example is the 45-ton, 300-hp. unit shown in Fig. 1. Their appearance follows the same general design regardless of size. Standard steel shapes such as plates, angles, I-beams, channels, etc. are employed in construction throughout. The usual grade of metal used is low-carbon steel. However, some work has been done with low-alloy, high-tensile steel.

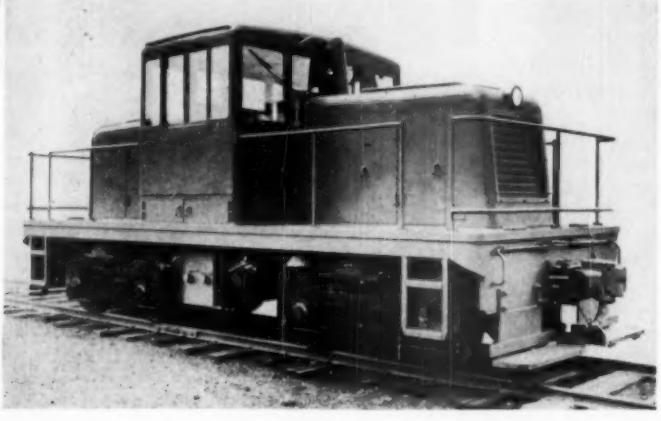

Fig. 1 Typical Diesel-electric industrial switcher

SUPERSTRUCTURE

Practically all industrial switchers are of the platform type. The first stage of construction is to assemble the platform, upside down as shown in Fig. 2. A deck plate is first laid out, then all the necessary holes, slots, radii, corners, etc. are burned or drilled according to requirements. The deck plate is then laid on a special assembly-floor plate embedded in the shop floor. The center sills and side channels are clamped in position and tack welded. Submerged arc welding is then employed using two heads mounted on a gantry as shown in Fig. 3. By this means both sides of a center sill or channel are welded at the same time. With the single head welder formerly used, considerable time was lost making the necessary setups and changes. Therefore, it was decided to design and fabricate a gantry-type welder mounting two heads and operating over the complete width of the bay. This permits the assembling of two platforms at a time for welding, and the running of two welds simultaneously. The two welding heads can be raised or lowered and are free to

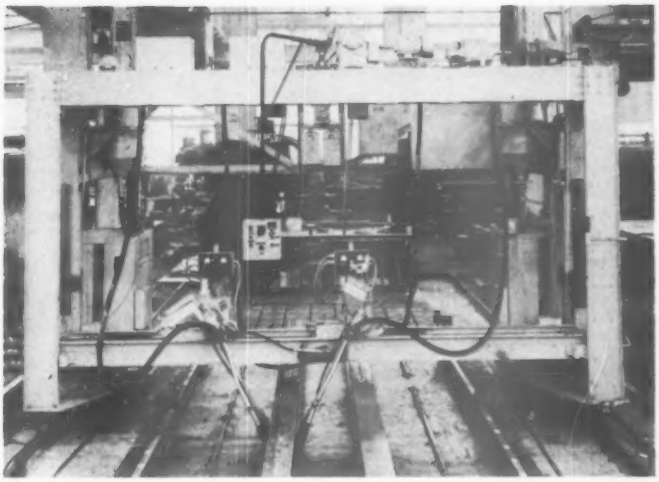

Fig. 3 Gantry welder with heads in position for welding platform center sills

move transversely. The entire gantry can move on guiding rails to any desired position in the bay. A motor with Thy-motrol control drives the selsyn generator transmitting power to two selsyn receivers which move the gantry along the track. The generator and receivers are electrically locked together and operate in unison. A rheostat controls the speed of the Thymo-trol drive which, through the selsyn generator, controls the speed of the gantry. Two 1000-amp. welding transformers and two flux recovery units are mounted on the frame. A positive flux feed under air pressure provides a continuous flow of flux to the nozzle end. The welding heads are automatically controlled. The speed range of the gantry is 8 to 240 in. per minute.

There are a number of good reasons for using submerged arc welding. The process is faster, i.e., more inches of weld per minute can be run. For instance, a single head deposits the same amount as three men could deposit in an equal time using the manual arc process. Other advantages are good ductility and shock resistance of the weld, and the absence of weld spatter. Higher current densities are used with submerged arc welding than with other methods. Retarded cool-off rates minimize distortion. Depth of penetration is greater.

When the center sills and side channels have been welded the clamps are removed from the platform, and the end frames, step supports, bolsters, gussets, fuel tank and other miscellaneous parts are tack welded in position. Two welders then do the balance of the welding by manual shielded arc welding, using type E6011 and E6020 welding electrodes. When all other welding has been completed, the centerplates are accurately located and welded to the bolsters. The welding is, for the most part, horizontal and vertical fillet welding. After inspection for weld quality, the frame is ready for shot blasting and the primer coat of paint.

Fuel tanks are entirely fabricated by welding. They are rectangular in shape and contain a series of baffles to prevent sloshing of the fuel. All tanks are pressure tested before mounting on the locomotive frame.

The subbase, which is next placed in position, houses the batteries, the reversing apparatus and resistors, and also acts as the floor of the main cab. Figure 4 is a diagrammatic sketch showing the relative location of the engine generator sets and apparatus subbase on the platform.

Parts for the main cab are formed in the sheet-metal section. In order that cabs be as uniform as possible, they are assembled and welded in fixtures. The stiffeners for the side sheets are spot welded prior to assembly. After the stiffeners have been spot welded to the side sheets and roof, and the parts assembled in the fixture and tack welded, the entire assembly is removed. Welding is then completed on the floor as shown in Fig. 5. The welds are made at the rounded corners in order to avoid the distortion that would occur if they were made in the middle of the sheet. Ball corner pieces, formed in a special fixture, are welded in place last.

Like other parts the control compartment is fabricated using standard materials of low carbon analysis, and assembled by spot welding and arc welding.

Much the same procedure is used in fabricating the engine cab. However, more work is necessary because of more doors, light mounting, radiator grill, louvres, sand box pockets and other miscellaneous parts. Base bars are welded to the platform to provide a means for bolting the engine cab in position as shown in Fig. 6.

Trucks used on switcher locomotives are entirely fabricated by welding. The heavy side frames are laid out and the necessary slots and holes burned. The top of the side frames, spring seats, and journal box pedestal surfaces are machined. The frames are then placed in a fixture and the transom, bolster plate, motor supports and centerplate are tack welded in position. Special care is taken to see that all dimensions are correct and that the center-to-center distance between the axles is within the allowed tolerance. The truck assembly is then removed and clamped to a large positioning table as shown in Fig. 7 where the welding is completed. This work is done with AWS-ASTM E6020 electrodes and the truck is turned so that all welds are made in a flat position. The journal box guides are welded into the truck frame after all the heavy welding is completed and the frame cooled.

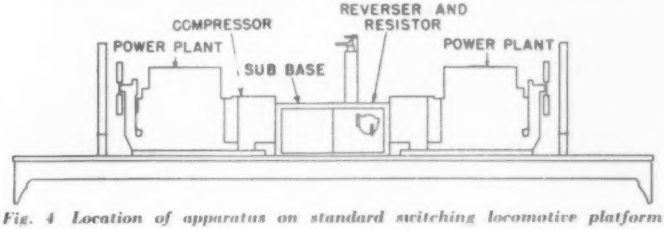

Fig. 4 Location of apparatus on standard switching locomotive platform

Fig. 5 Fabrication of main cabs for switching locomotives

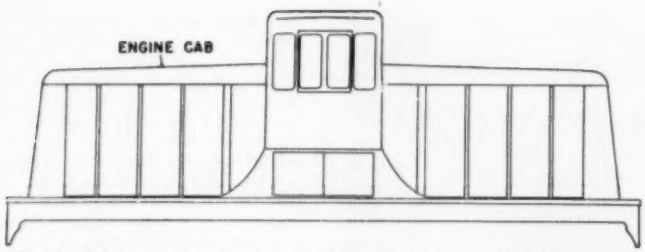

Fig. 6 Cab arrangement on standard steeple-type switching locomotive

ASSEMBLY

The various units (platform, cab, control compartments, trucks, etc.) are fabricated separately and brought together for final assembly on the erecting floor. Details of the assembly will not be discussed in this paper. Suffice it to say that the components are welded as required during the assembly operation. At this time guard rails, grab handles, brackets, clamps for piping, and safety treads, are welded in place. When the locomotive is completed it is inspected and sent to the test track for a trial run and final adjustments before delivery.

WELDING OPERATIONS ON A ROAD LOCOMOTIVE

Figure 8 is a picture of one of the largest single-cab straight electric locomotives ever built. It is an excellent example of the truss-type cab, now generally used on electric and Diesel-electric road locomotives.

In this type of cab two trusses, one on either side, transmit the superstructure load to the bolsters which rest on the trucks. The trusses are suitably braced horizontally, vertically, and diagonally, giving strength and rigidity. Figure 9 illustrates the process of fabrication and shows the general design of the truss and platform. The layout for tack welding of a truss is shown in the upper left. Two large angle irons were first properly spaced on the floor plate, then the bracing members were positioned and tack welded.

The complete welding on one side was done with E6020 electrodes. The short vertical welds were completed with E6010 electrodes. The entire truss was then turned over and finished on the opposite side as shown in the lower right of Fig. 9.

The fabrication of the platform was started by first positioning the center sills on the floor plate and tack welding the cross members between sills. The needle beams and side channels were next assembled. In this case the entire platform was assembled right side up. Horizontal and vertical welds were made, and the platform turned over to complete the welding of bolster plates, center plates, loading pads and miscellaneous parts. Figure 10 shows the completed cab before application of the side sheets. These were next placed in position and welded to the truss from the inside. The butt joints between sheets were welded vertically down on the outside and then ground flush.

TRUCKS

Customary practice in the United States has been to use cast-steel truck frames for passenger and freight locomotives. However, an increasing number of fabricated trucks are being made, including many for export. Figure 11 shows a heavy fabricated truck frame. The $3^1/_2$-in. thick side frames were first positioned in a fixture, and the cross ties, end-frame, extension and other miscellaneous parts were tack welded in position. All parts were welded together with a single pass, vertical or horizontal, to tie them together for removal from the fixture. The truck frame was then positioned each time by an overhead crane in order that all welding might be done in a flat or horizontal position. Two welders completed the welding on each truck. In the last step the frame was placed in a special fixture and the pedestal guides tack welded in place. The frame was then removed from the fixture and the welding completed. This procedure nullified the effect of any distortion that had previously taken place.

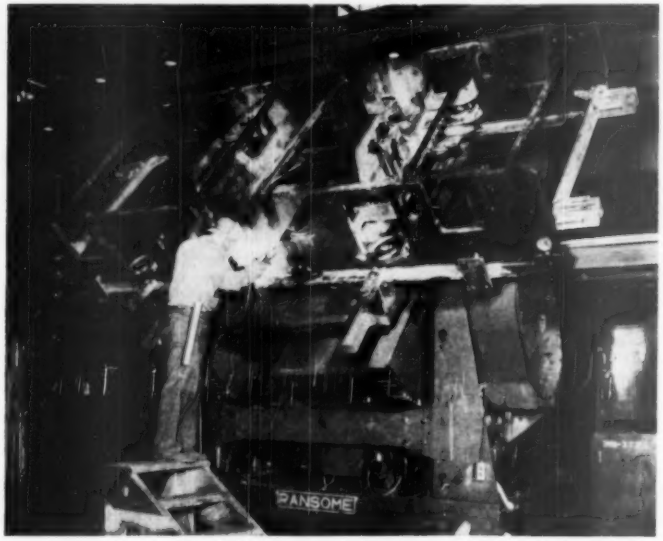

Fig. 7 Welding work on switching locomotive truck in positioner

Fig. 8 Five-thousand horsepower electric road locomotive

Fig. 9 Fabricating platform and cab trusses for large electric road locomotive

WELDING TECHNIQUES

One of the basic considerations in the design and manufacture of welded structures is to arrange the sequence of welding so that all heavy welds are completed before any work is done on parts requiring close tolerance. Eighty per cent of the welding in locomotive fabrication is done with 600-amp. a.-c. transformer type welders and E6020, so-called hot rod, electrodes. Flat positioned welding is used wherever possible because it results in better appearing and more uniform welds which can be made easier and faster. Alternating current with transformer type welders is used because this type of power supply results in a minimum amount of magnetic arc blow, which normally permits the use of larger diameter electrodes with correspondingly higher welding currents resulting in as much as 23 percent increase in welding speeds.

In the past year a change has been made from E6010 to E6011 electrodes for vertical welding because they can be used on a.-c. transformers. Deposition is faster and penetration sound. Definite efforts have been made to standardize on as few electrodes as possible to meet general requirements.

In a few instances other electrodes are used. The low-hydrogen type E6016, for instance, has been used to weld 1045 wearing plate to mild steel.

QUALITY CONTROL

Control of materials being used is a very important factor and one which is capably handled by the laboratory. All materials are ordered to specifications which designate the carbon, manganese phosphorus and sulphur content.

The size of electrodes used on specific applications is important and bears close observation. For instance it was found that using $^3/_{32}$-in. type E6020 welding electrodes for single- or first-pass welds in flat positions is poor practice. The excess porosity and poor root penetration of the weld obtained results in lowered strength of joints.

Quality of workmanship—assuming adequate equipment, facilities and proper electrodes—rests to a large extent with the welding operator. For the past three years all welders have been requalified yearly according to the classification of work they are doing. This is done by means of tests consisting of fillet welds in horizontal position with E6020 electrodes and vertical fillets with E6010 or E6011 electrodes. A sheet-metal test and tack-welding test are also used. Success in these tests indicates that the man is qualified for the particular work he is doing. If he fails a test he is not allowed to do that particular class of work until he demonstrates to laboratory personnel, after practice and retesting, that he can satisfactorily perform the type of welding required. Quality is checked by three individuals: an inspector who is required to inspect work before, during and after welding; a welding supervisor and a laboratory man responsible for quality control.

Special emphasis has recently been laid on the training of welding inspectors for their work. A special welding course, including practice welding followed by a dis-

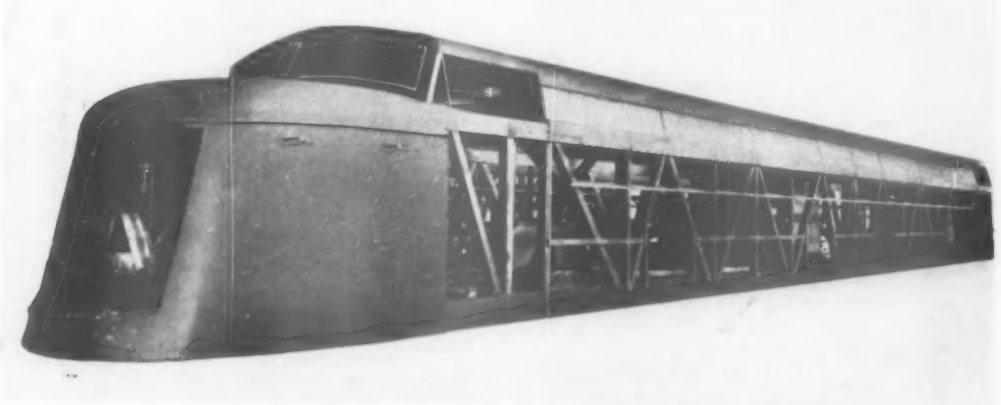

Fig. 10 Electric road locomotive cab before application of side sheets, showing truss work

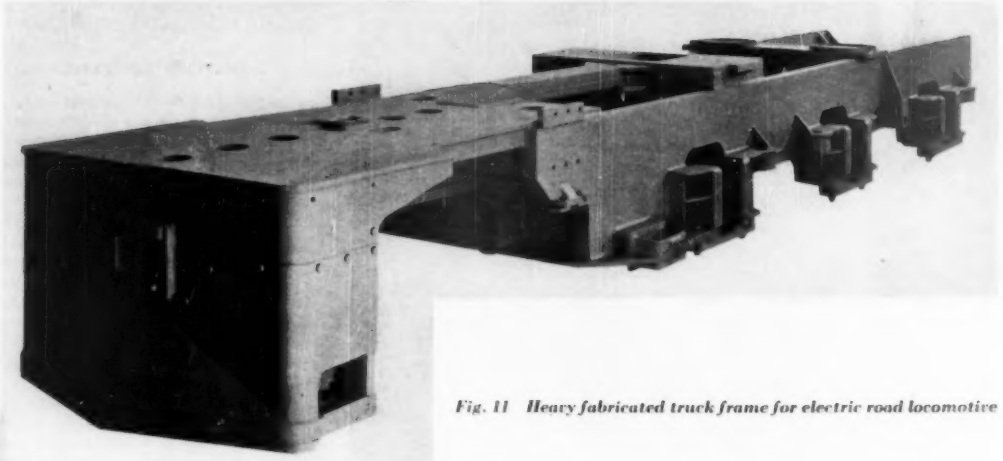

Fig. 11 Heavy fabricated truck frame for electric road locomotive

cussion period, has been given by laboratory personnel at our Erie works. The interpretation of welding symbols and questions pertaining to special requirements have been discussed at these instruction periods. The purpose of the classes was not to make finished welders out of inspectors, but rather to give them a clear conception of what welding really is and what they should look for in the line of defects.

CONCLUSIONS

Welding is a sound method, both economically and structurally, for fabricating locomotives. It permits greater flexibility in design than methods formerly used. It enhances the appearance of the finished product through greater ease of streamlining and elimination of unsightly projections. In fact, present designs of locomotives would be practically impossible without the use of modern welding techniques.

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Natural Gas Pipe Lines, Welding. Fabricating Record-Size

(*Continued on page 892*)

Designing Around a Process

Many new advances have been made recently in gas cutting in the development of standard machines or specialized machines to do specific tasks. Great economies are available in production through their use

by R. F. Helmkamp

WE CHOOSE to define "Designing Around a Process" as the study of the design of a product to capitalize fully on progress in such a proved production process as machine gas cutting. It is being used more and more in the development of modern products, and one of the most interesting processes applied in this way is machine gas cutting.

Thinking that is a generation behind does not maintain a healthy business. A high cost for any commodity starts the American engineer working night and day to solve the problem, and in many cases the solution is use of machine gas cutting to a greater extent. To stay out front, one must constantly think of improvement, which, of course, must be properly evaluated and thought out. Personnel with modern ideas and receptive minds will investigate ideas honestly and thoroughly, and an open-minded optimistic attitude, sparked by the right person or group, brings inevitable results.

When you first hear of a startling new development like the electronic tracing device, it is only human nature to plan to see it, find out what it can do and dream about how it may be applied to specific problems to lower the cost, expedite the work, improve the accuracy and handle the hitherto impossible jobs. Carried to completion, this reaction leads to a general increase in the efficiency of the plant.

Nowadays practically all larger industries have a laboratory. The smaller ones rely on the supervisory force to keep their ear to the ground for cost-saving processes and equipment. Some industries have employee suggestion systems designed to accomplish the same results. It is not uncommon to find industrial plants setting up pilot operations for exploratory reasons to uncover hidden advantages which may not be too apparent. While the pilot operations are in progress, complete data is kept and procedures are set up so that, when ready to be used in production, there will be a minimum of confusion. Industries that do this sort of thing develop the know-how that makes them leaders. There is a definite advantage in keeping abreast of developments.

The various gas companies and manufacturers of machine gas cutting equipment have developed general and specific information for the handling of all sorts of jobs. This information is available for the asking. Information is generally in simple form so that gas consumptions and cutting speeds allow the engineer to readily calculate the gas and labor costs. Production requirements suggest the machine and floor space involved, as well as the handling equipment. The work factor must be developed but it varies with specific shop conditions.

Equipment is available in standard high-precision shape-cutting units to handle many jobs, and where required it can be obtained with special features for highly specialized operations. Some of the larger equipment manufacturers will design and build equipment for specific jobs which are not readily accomplished with the so-called standard equipment and accessories. In such cases, the production job is studied, including production requirements, and in most cases it is interesting to note that an effective and economical means of applying machine gas cutting can be offered.

Machine gas cutting may be done as a single torch operation or it may be done with multiple torches on a single machine. Stack cutting may also be employed and is particularly advantageous on the very light cross sections, although some considerable work is being done on materials up to $\frac{1}{2}$ in. in thickness. A study of the results will decide which process to employ.

The advancement in machine gas cutting equipment has provided greater accuracy. Advantage may be taken of this greater accuracy through the use of the electronic tracing device (Fig. 1). This new tracing device follows a line established by a color contrast, making templets quite simple by comparison to the requirements of other types of tracers. The templet may be made by putting a line on paper, by cutting the templet out of paper and placing it on a contrasting background or by using white industrial plastic tape on a black background. The best color contrast is black

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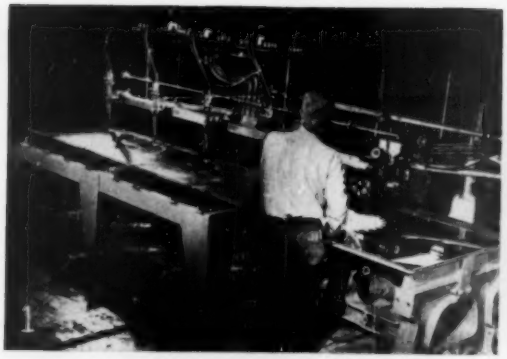
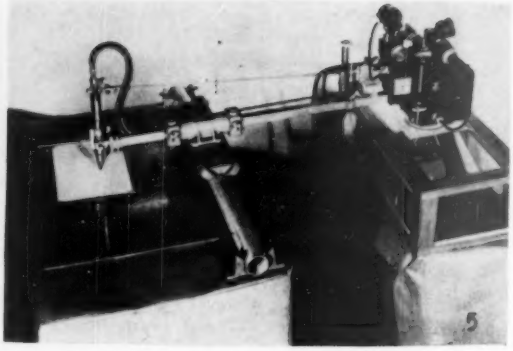
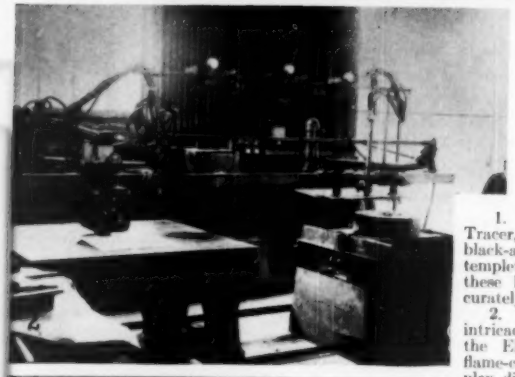
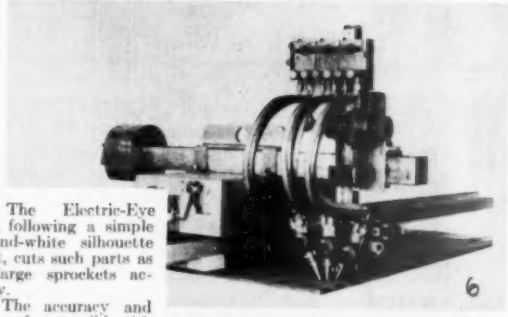








1. The Electric-Eye Tracer, following a simple black-and-white silhouette templet, cuts such parts as these large sprockets accurately.

2. The accuracy and intricacy of cut possible with the Electronic Tracer to flame-cutting used in complex dies and die backers with unprecedented economy.

3. Extrusion die backer and black-and-white drawing used as a templet for its production.

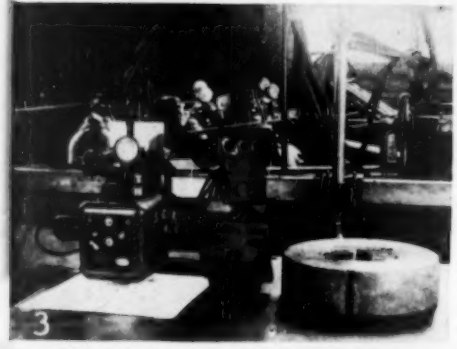
4. Portable shape-cutting machine in use in stack-cutting parts for railroad cars.

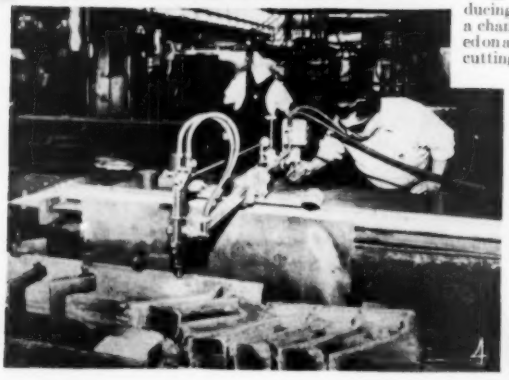
5. Portable shape-cutting machine set up with Electronic Tracer cutting part of a touring exhibit train.

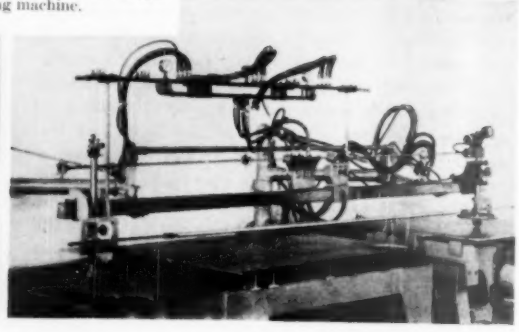
6. Three torch multi-bevel cutting machine.

7. Special attachment for cutting spiral plane on the face of the cut.

8. Mechanism for producing a constant bevel on a changing contour, mounted on a standard pantograph cutting machine.







and white although other combinations serve also. Paper templets may be filed like drawings for future use.

The intricacy of machine gas cut patterns has been considerably expanded by the development of the electronic tracing device. It readily handles work in some cases considered impossible or impractical to do by the other types of tracers in general use. Theoretically, the manual tracer is the most versatile but the human element exerts its influence and results in the cut piece will vary. The magnetic tracer will reproduce accurately but some limitations are imposed when highly intricate shapes are desired. The same holds true for other types of strip templets. The cost of metal templets is considerably greater than paper templets. The average templet cost for the electronic tracer is approximately 10% of the average templet cost for all other types of tracers in use. This saving in itself helps pay for this unit in a comparatively short time.

The accuracy of reproduction of a templet that is possible with machine gas cutting equipment has been recognized by die makers for the shaping of extrusion die backers (Figs. 2 and 3), forming dies. The die men are designing around the machine gas cutting process, since the electronic tracer has proved its dependability and faithfulness of reproduction. Precision machines, torches, and tips are vital adjuncts to the tracing device, and with them, work is being done to very close limits of accuracy. One group set out along these lines with a goal of accuracy within ten one-thousandths of an inch, and it appears that they are going to reach it.

Within the past year there has appeared on the market a portable shape-cutting machine, with extreme accuracy (Fig. 4). This machine may also be equipped with an electric eye tracer (Fig. 5), which enhances its value for special work. So equipped, this unit is now on tour throughout the country on an industrial-exhibit railroad train.

Joint preparations for welding may require a single bevel, a bevel and land, a double bevel or a double bevel and land. These requirements can be met with equipment which (Fig. 6) is now standard and readily available, which delivers any of the combinations required rapidly, economically and accurately.

Other jobs may require a constantly changing bevel, and equipment has been developed (Fig. 7) which will produce the required result smoothly and easily. The same features are available in the nature of an attachment for standard cutting machines. Automatic welding of major assemblies calls for correct and closely controlled joint preparation, and it is of interest that machine gas cutting equipment (Figs. 8, 9 and 10) is available, using a torch revolving mechanism interconnected with the torch, so that with a tip set at the correct angle, it will maintain a constant bevel along any contour that will cut a constant bevel on an irregular contour. This is a development many fabrication engineers should find valuable in design problems.

Bridge engineers of Bethlehem Steel have designed a self-cleaning type of expansion joint (Fig. 11) which specifies that the slot on the top surface be $^1/_4$ in. and at the bottom surface be $^1/_2$ in., no matter what the plate thickness. This type of slot is produced with the same equipment used for constant bevels on irregular contours (Figs. 8, 9 and 10) using a double tip. Such equipment may be added to the true pantograph type of gas cutting machine as an accessory.

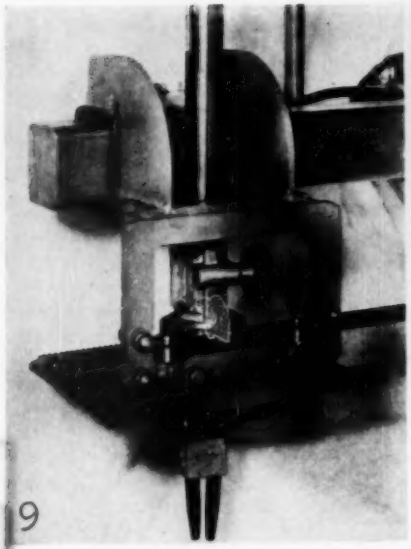
Silicon steel, used in bridge construction, may be satisfactorily machine gas cut when correct procedures and equipment are used. The bridge engineers have been able to design around the gas cutting process by developing an answer to cutting this problem steel (Fig. 12). The answer is to anneal the plate as the cut is in progress. Development of this definite procedure has made accurate, dependable machine gas cutting a valuable tool in this industry.

Specialized machines to do just one job, and do it well, find their place in industry when production requirements are sufficient to warrant their cost. A good example is a machine (Fig. 13) designed to cut rectangular openings in a cylindrical member. The machine requirements were to gas cut two or four such openings at a time, spaced as desired, and the production requirements for the job warranted development of a special machine for the single purpose at hand, as economy and efficiency could be considerably improved.

A further aid to the design application of the process is that gas cutting machines may now be obtained with semiautomatic or fully automatic controls, as may be required (Figs. 14 and 15). In some cases quick-shut-off requirements apply only to the cutting oxygen stream, and in others it is applied to the preheat gases also. Solenoid valves (Fig. 15) offer a suitable medium for this purpose, and there has been developed a line of solenoid valves for a single shut-off for multiple torches as well as individual valves for individual torches. Controls, when using these valves, are located at the operator's station.

Another development provides a means of raising and lowering the cutting torches from the operator's station (Fig. 16). With this arrangement, torches may be used in the vertical or angular positions, transverse or at right angles to the mounting bar. The arrangement is such that the raising or lowering is done on the center axis of the torch, so that when bevel cutting is being done no distortion of the cut line is produced. By means of an adapter the unit may be mounted so that the torch can produce compound angles. These units are motor-driven and the torches may be raised and lowered individually or all at once from the operator's control station. The units are equipped with special over-run couplings that prevent damage when they approach either the high or low position.

The forge shop and the foundry have found a useful tool in equipment designed to do what is generally termed heavy cutting. The machining of a heavy type of forging is sometimes a time-consuming operation. When designing around the machine gas cutting process the engineer finds he has an interesting advantage



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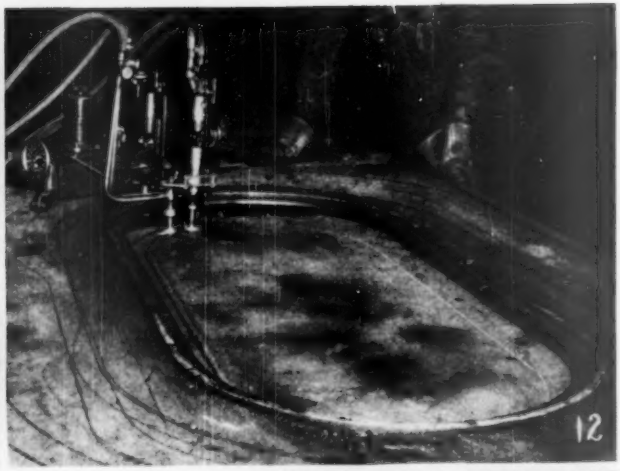

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9. Torch end of constant bevel mechanism (Fig. 8). Double tip shown is used in production of a special expansion joint sketched in Fig. 11.

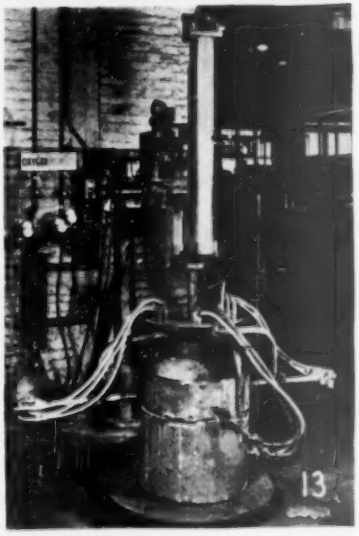
10. Tracer end of constant bevel mechanism, which maintains rotation of the tilted torch to hold a true constant bevel on a changing contour.

11. Self-cleaning expansion joint.

12. Cutting silicon bridge steel, with an annealing attachment traveling immediately behind the torch to eliminate hardening effects of cutting temperatures.

13. Special machine developed to cut multiple square openings in a cylindrical part.

14. Eight-torch automatic control installation on a standard pantograph cutting machine.



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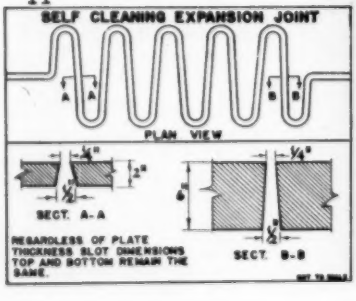
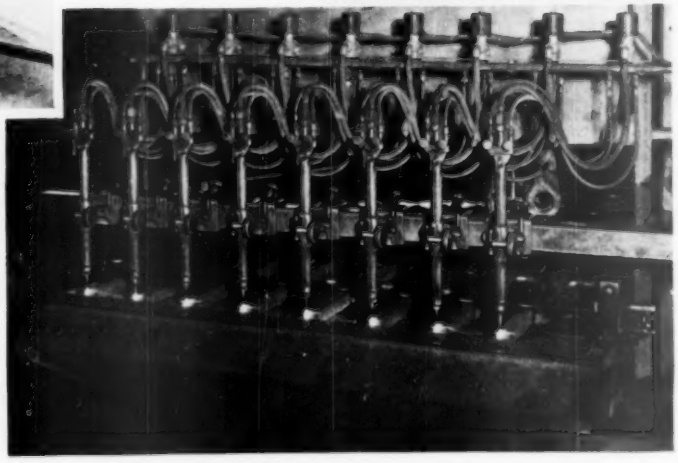
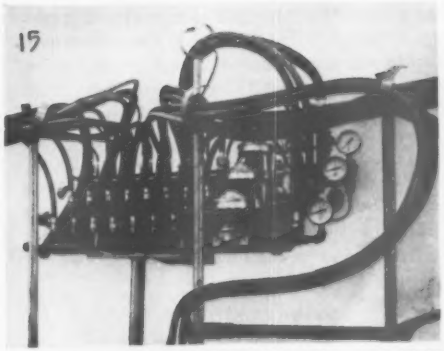
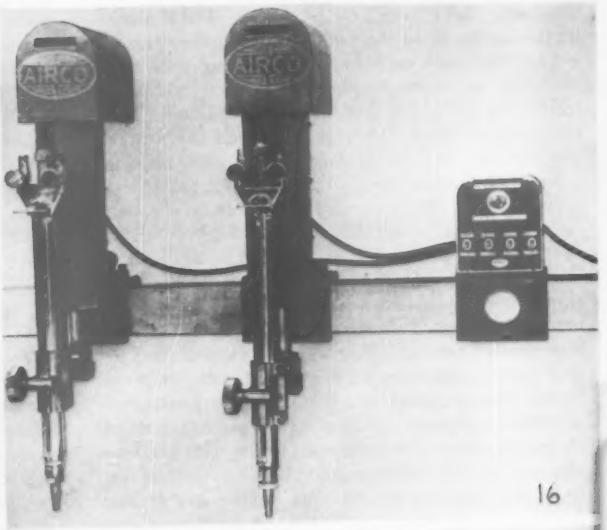
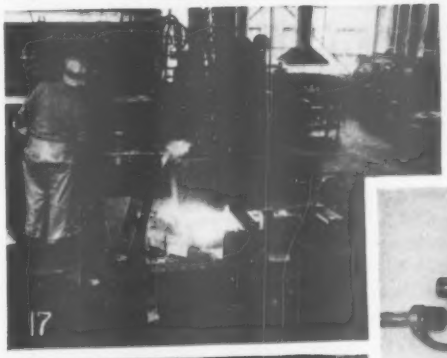
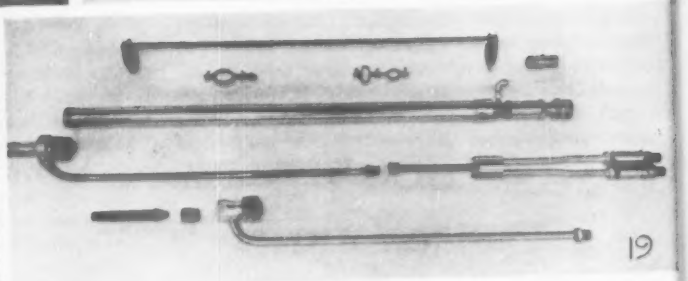


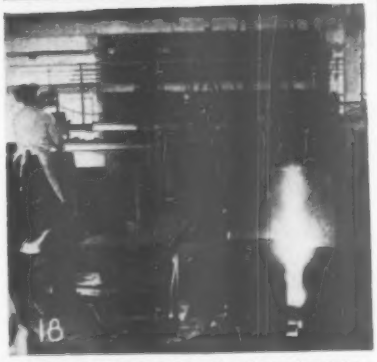




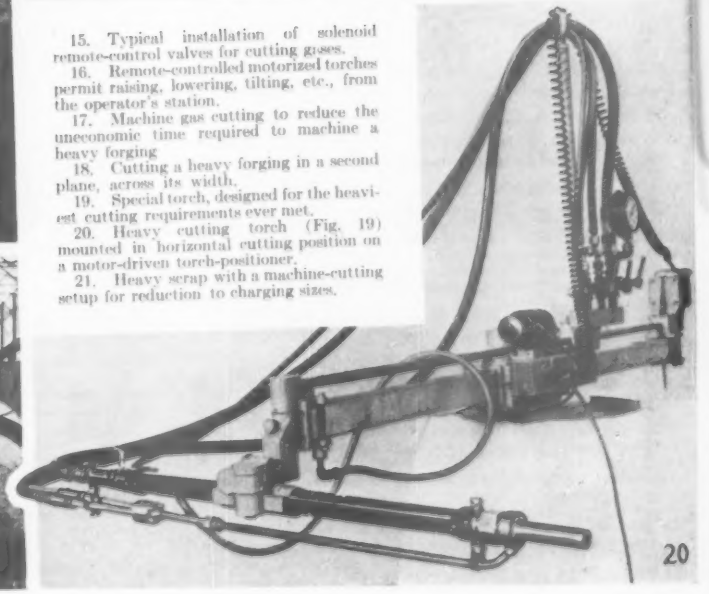








15. Typical installation of solenoid remote-control valves for cutting gases.
16. Remote-controlled motorized torches permit raising, lowering, tilting, etc., from the operator's station.
17. Machine gas cutting to reduce the uneconomic time required to machine a heavy forging.
18. Cutting a heavy forging in a second plane, across its width.
19. Special torch, designed for the heaviest cutting requirements ever met.
20. Heavy cutting torch (Fig. 19) mounted in horizontal cutting position on a motor-driven torch-positioner.
21. Heavy scrap with a machine-cutting setup for reduction to charging sizes.



since he can shape a piece (Figs. 17 and 18) within ready machining tolerance at a fraction of other present costs involved. Gas cutting may be done in several planes by turning the piece, making this a simple operation.

The equipment manufacturers, keeping pace with industrial requirements, have developed a cutting torch (Fig. 19) whose thickness capacity has not been completely explored since it is far beyond any requirement to date. The water-cooled high capacity machine gas cutting torch is designed with an external quench type mixer for the preheat gases. Cutting tips are designed so there is no danger of preheat gases entering the cutting oxygen stream, and tips can be had with an orifice diameter up to 1 in. In operation, this torch far surpasses anything yet available and has a record of cutting remarkable thicknesses with very low oxygen consumption per ton. This torch is in use in what we may call the largest single gas cutting installation in the world. It has a record of cutting heavy scrap at a rate of 4000 tons per month with an average of 300 cu. ft. of oxygen per ton. The acetylene consumption averages about 1 to 10 for the oxygen. This is a machine installation designed around the machine gas cutting process.

This super machine cutting torch may be used on various cutting machines and may be operated in any position. It may be motor-driven up or down and in and out (as shown in Fig. 20), or hand cranked, as desired. It may be readily adapted to shape or straight line cutting.

In the steel business, mining the property is profitable business today. Heavy scrap, formerly buried because there was no economical method of salvaging it is now being gas cut to usable size (Fig. 21). The reduction of such scrap to size may be accomplished by gas cutting with the large capacity hand torch assisted by a lance or by the machine torch method. Existing conditions suggest the method to use. The hand torch method has the advantage of tackling the problem on an "as is" basis. When machine gas cutting is employed the work must be positioned, requiring crane service. This is a highly profitable development for the steel industry and foundries that are confronted with this problem.

CONCLUSION

Today we find diverse types of industry solving numerous production problems by designing around the machine gas cutting process, with the modern and precise equipment which has become available in recent years and months. In some cases, the designer achieves economy and efficiency to a marked degree, on more or less "standard" designs, and in other cases, he is able to use a simpler and less costly design for an unusual product by designing with gas cutting. In the final analysis, it will pay the designer to remember the existence of the process, familiarize himself with its potential uses, and combine that knowledge with imagination. Many of his problems will disappear with such an approach to designing around machine gas cutting.

(*Continued from page 886*)

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Jigs and Fixtures for Inert-Gas Arc Welding

Need for jigs and fixtures discussed and the necessity to design these fixtures for the newer welding processes involved as well as for the product to be turned out

by H. A. Huff, Jr. and A. N. Kugler

THE importance of jigs and fixtures employed in welded construction has been amply demonstrated and widely discussed in the literature. There is little question as to the necessity for, and value of, jigs and fixtures for production welding on large scale operation. There may, however, be some question as to the necessity for these devices on smaller scale production. In such instances, the requirements of the individual welding process may very well dictate the necessity for a welding jig or fixture.

The inert-gas arc-welding processes, encompassing inert gas-tungsten arc welding and inert gas-metal arc welding, with consumable filler wire impose certain requirements not commonly encountered in other welding techniques. Therefore, it has become necessary to adjust the thinking on jigs and fixtures to suit these processes. In some instance, it is necessary to design specifically for the process involved as well as, of course, the product to be turned out.

The inert-gas arc-welding processes are characterized by rapid heat input and rapid cooling. With certain metals, it is possible to fuse square-edge butt joints without filler metal and still produce a joint with reinforcement at the root and face. To accomplish this result, it is necessary to employ suitable jigs and fixtures whether or not the production involved is small or large. Further, when welding with direct current the influence of magnetic interference (arc blow) is perhaps more serious than with other welding methods. This imposes the requirement for extensive use of nonmagnetic materials in the jig structure, for those classes of work which require direct current. Still further complications are created when welding with alternating current in those instances where continuous high frequency is employed. Thus, it will be seen that while the problem of jigs and fixtures is fundamentally the old one that has been long present, certain variations are imposed by these techniques or for new approaches.

It has been noted that heat input and cooling, in the weld cycle, are very rapid. As a result thereof welding speeds are of a high order, particularly on square-edge joints without filler metal. High welding speeds cannot be employed without appropriate edge preparation. The most critical condition is encountered on square edge butt joints in sheet metal In this connection, it must be remembered that with mechanized and automatic welding techniques, welding speeds may approach and exceed 120 in. per minute (0.014-in. thick stainless steel or silicon transformer steel welded with d.-c. S.P. and He). The edge preparation under these circumstances requires intimate metal contact for the entire length of the joint. If a gap is permitted to exceed a value of the order of 0.003 in. on this light material, it will be found that the arc will burn through in that zone, thereby destroying the joint. It is appreciated that this requirement for accurate joint preparation involves added expense. However, if these high welding speeds are to be attained with a minimum of rejections, then this condition must be fulfilled. Furthermore, the joint should be square; any reverse beveling or "knife edging" will likewise lead to burn-throughs and failures. While the requirement with respect to joints employing filler metal are less critical, the same principle applies, but to a lesser degree.

Virtually all welds made by these processes are required to show complete penetration throughout the metal thickness and this in turn raises the question of weld backup. Since the inert-gas arc processes are capable of handling, without any flux, those metals which normally require welding flux, this feature introduces added problems at the root of the weld. Actually the problem of backup is not isolated but it should be considered along with the means employed for welding and clamping the elements of the joint. However, certain essential features may be outlined here.

On stainless steel, killed mild steels, nickel and its alloys and copper and its alloys, the square groove butt

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joint may be made in thicknesses up to about 0.020 in. employing a flat strip backup provided that high welding speeds are employed. This, of course, carries with it the necessity for accurate joint preparation and fit-up. Where these welding speeds cannot be attained for one reason or another, then it is considered good practice to resort to a grooved backup. The groove in such cases should have a width about three times the thickness of the sheets being welded. The depth of such grooves will range from 0.003 in. to one-half the thickness of the plates and is a function of welding speed, current and shielding gas employed. The actual value of depth is best determined experimentally for each individual case; it is a simple matter to start with a shallow groove, run a few experimental seams and if these are unsatisfactory deepen the groove. The necessity for a groove particularly at slow welding speeds will be apparent when it is realized that at slow speeds a larger puddle is obtained. This puddle, if carried on a flat backup, would tend to force up the edges of the sheet, thus creating an unreliable groove condition.

As metal thicknesses increase, the possibility for omitting back-up bars increases, but the point of division varies with different metals. Thus, at about $^1/_{16}$ in. thickness in stainless and similar metals, back-up bars may be omitted. With aluminum and similar metals, this is more of the order of $^1/_8$ in. Of course, in the case of aluminum, the flanged edge butt joint may be employed without back-up and without separate filler metal and still achieve a thoroughly penetrated weld.

Under some conditions, it is desirable to introduce a gas at the root of the weld to prevent oxidation at this point which is remote from the point of application of the shielding gas. In jigs employing backup, it is possible to perforate the backup to introduce the shielding gas through these perforations. Under other circumstances, a jet of gas is played on the root of the weld. The conventional inert gases, helium and argon, are commonly used and in addition, particularly on stainless steel, hydrogen is some times burned at the root of the weld, thus producing a reducing atmosphere.

In semimechanical and automatic operations, it is possible to carry a traveling backup in the form of a roller or shoe which rides under the joint at the root of the weld directly under the arc and the molten pool. These rollers may be grooved or flat and are subject to the limitations outlined previously under the continuous backup bars.

The interrelation between the backing of a weld and the hold-down elements of the jig arrangement has been previously discussed, briefly. Actually, both the backing features and the hold-downs are largely dictated by shape of the part to be welded. In this connection, it is well to remember that either the backing member may be held fixed and the hold-downs made movable, or the hold-downs held fixed while the backing is made movable. Appreciation of this point will help solve some of the more complicated jig problems. Reference has also been made earlier to the necessity for the use of nonmagnetic materials in the jig structure and the hold-down or clamp bars are points at which nonmagnetic materials may prove helpful. Aluminum bronzes possess high strength and at the same time are nonmagnetic, hence find extensive use in this field. Another means of overcoming the magnetic problem is to face the magnetic parts with a nonmagnetic material such as aluminum bronze. The use of nonmagnetic jig parts is desirable notwithstanding the use of any magnetic shielding in the arc itself.

The clamp bars of the jig must fit close to the joint but not extend beyond the edge of the groove in the backup. This latter point should be obvious when it is realized that pressure beyond the edge of the groove is likely to cause depression of the sheet edges. In addition, the hold-down bars must fit the various elements of the joint closely. If a bar fails to contact the sheet, when the arc traverses the area, the welding heat will cause the sheet to lift and create distortion which may throw the edges out of plane resulting in poor weld or a "burn-through."

The matter of close fit of the clamp bars is exceedingly important and warrants more detailed consideration. It has been found by experience that it is more desirable to break the clamp bar into segments rather than employ one solid piece. A solid clamp bar frequently exhibits the tendency toward "bridging," that is, touching on two points while leaving the intervening zone without control. By employing segments, bridging is eliminated and continuous, positive clamping assured. These segments, however, must fit closely together and the gap between them should not exceeded 0.003 in. Another means of assuring uniform pressure is to provide springs between the segments of the clamp bars and a backup bar is illustrated in Fig. 1. A modification of this design substitutes adjusting screws for the springs.

In addition to the direct pressure secured through the clamp bars and the backup element, a degree of lateral pressure is also needed to assure that the joint is maintained in metal-to-metal contact. The degree of this lateral pressure, however, is quite critical since excessive pressure can cause the joint to spring upward, whereas, insufficient pressure might permit the existence of gap. In this connection, the best guidance is to use just sufficient pressure to maintain metal-to-metal contact without distorting the joint from its proper plane.

The design of the clamping arrangement, particularly with respect to cross section of the bars is of great importance. The edges of these bars facing the weld

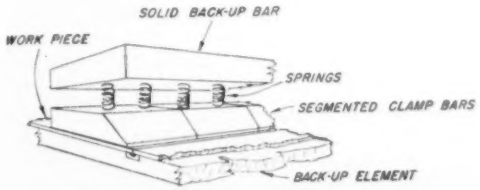


Fig. 1 Spring loaded, segmented clamp bars

zone should be beveled to a maximum angle of 45° as measured from the plane parallel to the center line of the weld passing through the edge of the clamp bar. It is also desirable to provide a shoulder at the base of this bevel since feather edges will tend to burn away. At this point it seems appropriate to caution the designer in selecting the size clamp bars. After all, their function is to exert appreciable pressure on the parts to be welded. Therefore, the selection of light elements for clamp bars is hardly in the interests of good jig design. It is far better to err on the side of heavier clampbars than lighter elements. Heavy bars may be cumbersome but light bars can rarely be made strong enough to exert the required force.

In some instances, it may be necessary to fabricate the clamp bars out of several structural elements employing, of course, welding for the fabrication. Such welded assemblies may well be stress relieved before placing in service. This recommendation is based upon the fact if placed in service as-welded, the continuous heat of welding in production may cause unequal distortion in welding resulting in poor performance as a clamp bar. This is of even greater importance for elements which must be subjected to high work factors on production operations. Water-cooled clamp bars and backup elements which are frequently used also fall into this category.

Cylindrical butt joints impose special problems, particularly if the cylinder is a closed one with limited access to the inside. The various problems encountered may be considered progressively starting with the cylindrical joint, the interior of which is completely accessible. In this instance, it is possible to employ an expanding backup element at the root of the weld. This serves to force the two sheets of the joint into accurate alignment and if lateral pressure is employed by bolting, springs, etc., then metal-to-metal contact may be assured. The backup element may be flat or grooved as discussed previously. The joint thus assembled may be welded manually, semiautomatically or with fully-automatic equipment and when completed, the backup element retracted and removed.

On cyclindrical containers with limited accessibility,

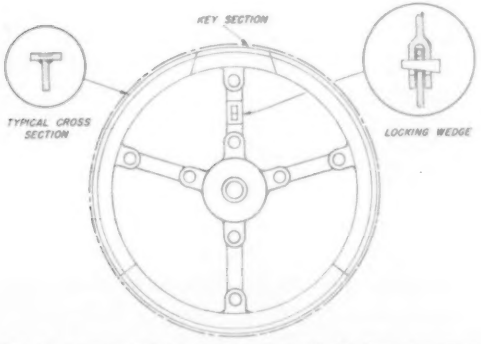


Fig. 2 Segmented, internal collapsible backup structure

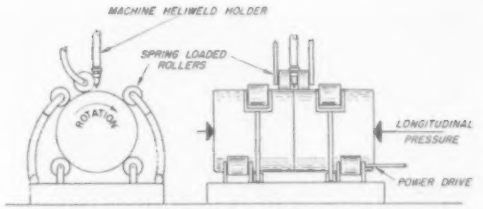


Fig. 3 Schematic of jig for welding cylindrical containers without backup

a segmented, collapsible backup may be employed. This type of backup is frequently inserted in one-half of the assembly loosely, following which the second half is assembled in position and the backup tightened to establish alignment. Lateral pressure may be applied by any convenient means. As in the previous instance, welding progresses by any of the accepted methods following which the key segment of the backup element is extracted through the access hole. With the key segment out, the balance of the segments fall away rapidly and are readily withdrawn from the work (see Fig. 2).

For the welding of butt joints in cylindrical containers which are virtually inaccessible on the inside still another approach is available. In this case, however, accurate preparation of the ends of the stamped halves is of the utmost importance to assure accurate fit-up. Prior to insertion of these assemblies in the jig, it is necessary to align and tack weld them outside of the jig, the number of tack welds being dictated by the size of the parts. The jig illustrated schematically in Fig. 3 employs a means for providing pressure on the longitudinal seam to maintain the required metal-to-metal contact; this may be achieved with mechanical, hydraulic or pneumatic clamps. In the lower quadrants of the jig are four rollers, two on each side to support the cylindrical element. In the upper quadrants, two arms are provided to hold the cylinder in contact with the lower rollers. One of the lower rollers is power driven at an appropriate speed to produce the weld. At the top center line, ahead of the arc, are provided two rollers under sufficient loading to cause the butting edges to the sheets to maintain their alignment. In this manner the two edges of the sheet are presented to the arc in substantially a plane condition. Under conditions of this nature, it is sometimes desirable to introduce a jet of gas at the root of the weld.

While the mechanical features of a jig in so far as holding and movement are concerned are of great importance, other features related to the actual welding operation require equal consideration. One of the more important of these features is the problem of arc starting. Since the bulk of these jigs and fixtures are for mechanical and automatic welding setups and it is necessary to produce the complete weld without defects at the start and finish, arc starting requires special consideration. Actually, the problem of arc starting is closely related to the type of equipment employed for the welding, hence a review of a number of the various

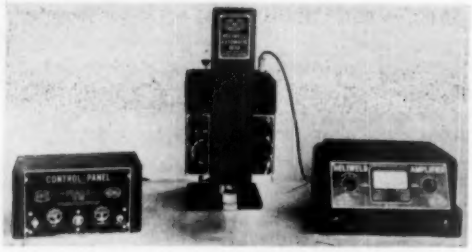


Fig. 4 Automatic heliweld head which provides for arc starting without high frequency

methods employed will be helpful in understanding the relationship of this phase to the jig design.

The simplest (and perhaps first method of initiating the arc with mechanized equipment) is to short the electrode to the work with a carbon electrode. This, of course, is not an automatic operation and in consequence is suitable only for limited production work. It has the further disadvantage that in the shorting operation the tungsten becomes contaminated and the arc resulting therefrom will be unstable for an appreciable length of time.

Going to the other extreme, there is available the fully-automatic head which incorporates a mechanical-electrical arc-starting device. This is illustrated in Fig. 4. All that is necessary with this equipment is to establish the desired arc voltage (with a given gas and welding current this establishes the arc length) and then by the simple operation of a switch initiate the welding operation. The machine, by means of electrical and mechanical controls, advances the electrode to the work immediately withdrawing and establishing the arc to the required length. This automatic head has other features such as maintenance of the set arc voltage regardless of the contour (within limits) of the workpiece.

On some classes of mechanized welding it is not necessary to employ the fully-automatic head. In such instances, a simple machine holder suffices and to it may be attached substantially the same equipment used on the automatic head—the mechanical-electrical touch starter, as pictured in Fig. 5. The operation of this device is essentially the same as that described for the automatic head. It should be noted that if the automatic head or the touch starter are used for alternating current, only balanced a.-c. (high open-circuit voltage) type of equipment should be employed. This type of equipment must not be used with continuous high frequency.

High frequency is also used for initiating the arc under some conditions. In d.-c. welding, the conventional type of oscillators do not give reliable starting. In order to use high-frequency starting with direct current, it is necessary to employ a specially designed oscillator and equipment to give consistent results. The balanced a.-c. type of equipment, however, includes a three-cycle impulse of high frequency for starting and this is adequate to initiate the arc with this welding-power source. Of course, for a.-c. welding with continuous high frequency the starting problem is taken care of with the continuous high frequency.

When welding square-groove butt joints automatically, if the arc is initiated at the edge of the joint, a short distance will be burned away before stable heat conditions are established. This may also lead to contamination of the tungsten electrode which further renders the arc unacceptable. A similar condition is created at the end of the seam. One means of correcting this condition is to apply short tabs of the same composition

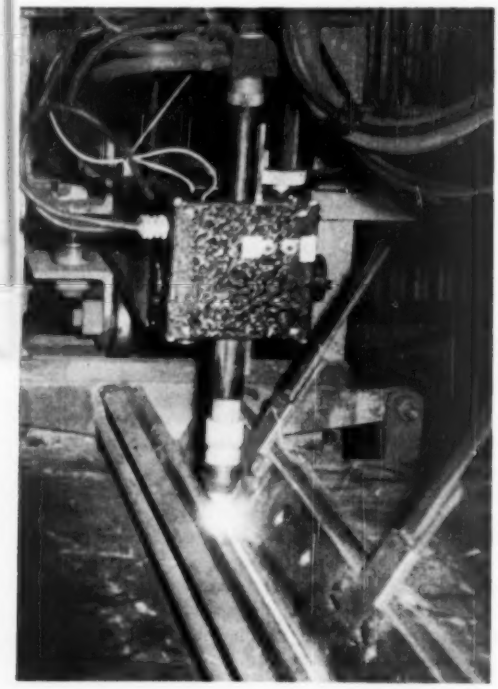


Fig. 5 Touch-starting device for machine welding

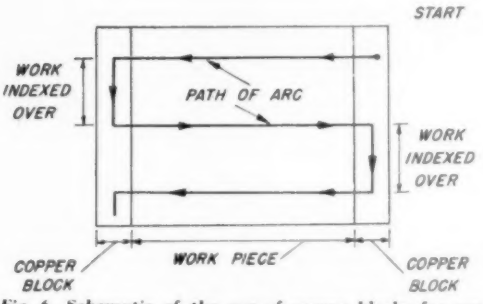


Fig. 6 Schematic of the use of copper blocks for arc starting and continuing the arc

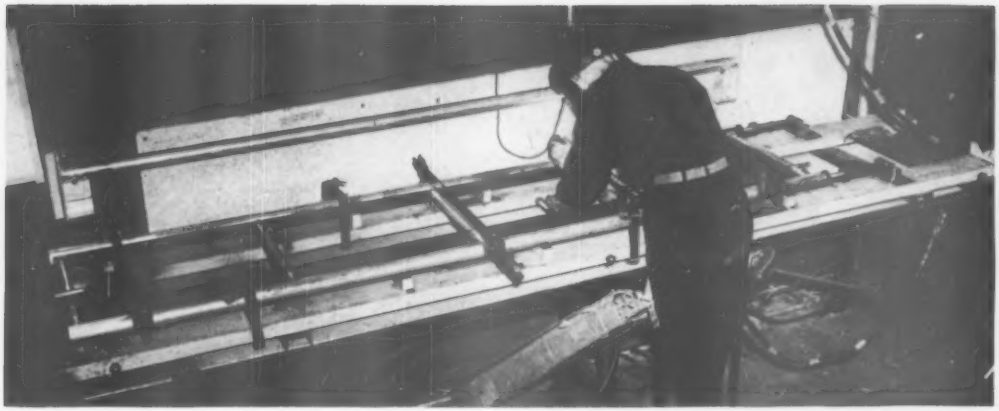


Fig. 7 Subassembly jig for tubular television mast

and thickness as the metal to be welded at the start and finish of the joint. The arc is initiated on the tab, carried along on to the joint and at the other end from the joint off, on to another tab. For satisfactory results, it is important that these tabs maintain metal-to-metal contact with the workpiece. Obviously, these tabs must be removed before the welded unit may be further processed or placed in service. In addition, there is always the possibility for electrode contamination from these tabs.

A more satisfactory technique for initiating the arc is to insert in the jig, copper blocks at the start and finish of the joint. These blocks are of appreciable size and of a thickness greater than the parts to be welded. However, the upper surface of the block is so placed that it falls in the same plane as the weld seam. The arc is initiated on the copper block; carried on to the joint and from the joint on to the copper block at the leaving end. Such copper blocks have very satisfactory life in service because their mass enables them to absorb the heat without excessive burning. An interesting modification of this starting method is pictured in Fig. 6 where the arc must be carried continuously over a number of welds. Here it is started at a copper block, progressed across the joint where it meets up with another copper block, and the arc is indexed the required distance over, and the arc is carried back on the workpiece for the required length of weld where it encounters another copper block, and this sequence is continued until the required number of welds are made.

The welding ground may seem like a perfectly obvious detail, yet its application to the workpiece or jig is an important phase of this work. In line with good welding practice, it should be applied as close to the point of welding as is possible. Preferably, the ground circuit should not be required to travel through loose connections such as bearings. A spring-loaded copper strip or "brush" contacting the workpiece continuously during the welding has been found to be very satisfactory. On cylindrical workpieces, this brush merely "rides" the cylinder as it rotates or is traversed for longitudinal seams.

The best way to illustrate these various fundamental points in the designing of jigs for inert-gas arc welding is to examine typical, as well as unusual examples of this class of work. Figure 7 shows a typical assembly jig such as might be used for any welded assembly. In this particular instance it is employed for assembling tubular elements which are welded into sections of a television tower. Observe the hold-down features for positioning the various tubular sections. Welding in this instance is performed by manual inert gas-tungsten arc welding, using the balanced a.-c. equipment. The jig employed in this illustration is only for tack welding—the complete welding being performed outside the jig. Other roughly similar jigs are used to com-

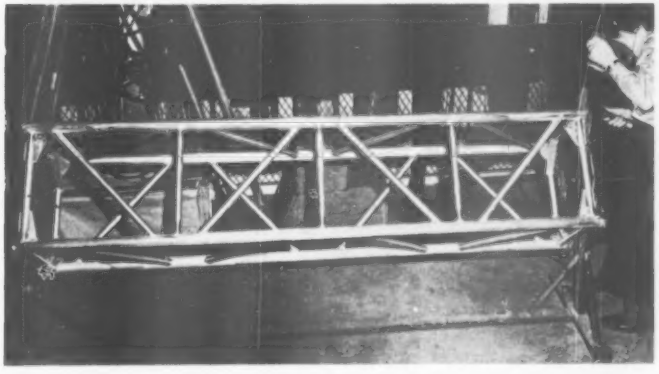


Fig. 8 Assembly jig for welding television mast

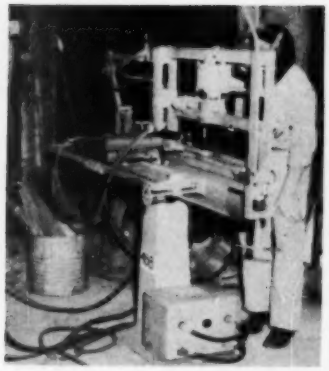


Fig. 9 Jig for longitudinal seam in type 308 stainless cylinders—22 ga.

Backup rigid, clamp bars applied with hydraulic pressure. Lateral pressure applied with screw

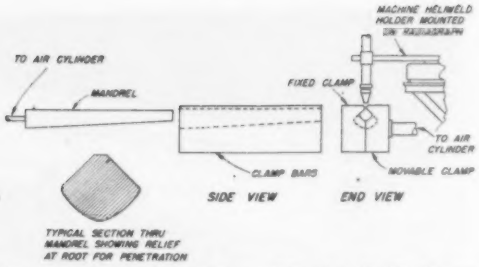


Fig. 11 Jig arrangement for welding longitudinal seam in aluminum chair leg

bine the subassemblies into the final welded structure. A trunion mounted assembly welding jig is illustrated in Fig. 8; the unit here shown is one section of the television tower.

A somewhat more complicated jigging problem, but none the less, one commonly encountered is illustrated in Figs. 9 and 10. The parts here being fabricated are stainless-steel cylindrical containers about 6 in. in diameter and 20 in. long. They are made of A.I.S.I. Type 308 stainless steel, 22 gage. First, the longitudinal seam is made with the mechanized setup and jig—Fig. 9. Following this, the stamped heads are welded to the shell as pictured in Fig. 10. The longitudinal seam is a square groove butt joint. The backup element is fixed while the clamp bars are movable and forced into position by means of the hydraulic cylinder which may be seen above the holder. Observe that lateral pressure is applied by means of screw clamps which may be seen just ahead of the track for the Radiagraph. In this instance, welding is performed with a manual Heliweld holder mounted on a conventional straight-line cutting machine. Direct current, straight polarity is employed to weld the square butt joint with a current of about 60 amp., a welding speed of 45 ipm., helium flow 18 cfh. and tungsten size, $^1/_{16}$ in. Run-in and run-out tabs are employed at each end of the longitudinal seam.

The circumferential weld, Fig. 10, is again a semiautomatic operation with the hand holder positioned above the seam while a motor-driven turntable causes the parts to rotate under the arc. This edge joint between the cylindrical side sheet and the stamped heads is welded with direct current, straight polarity at about 80 amp. and a welding speed of 55 in. per minute. Tungsten size and helium flows are the same as noted above for the longitudinal seam. In both instances the arc is initiated by means of high frequency supplied by the oscillator which may be seen under the jig in Fig. 9.

Regular geometrical shapes such as cylinders are relatively simple to set up in jigs. When irregular shapes are encountered, more ingenuity is required to devise adequate clamping arrangements. An excellent ex-

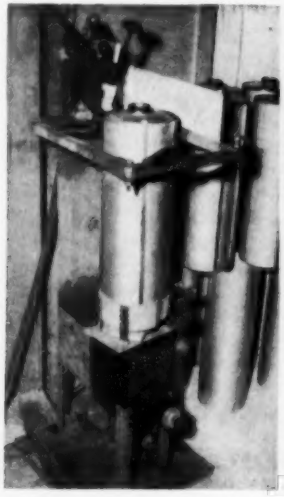


Fig. 10 Rotating jig for welding heads using edge joint

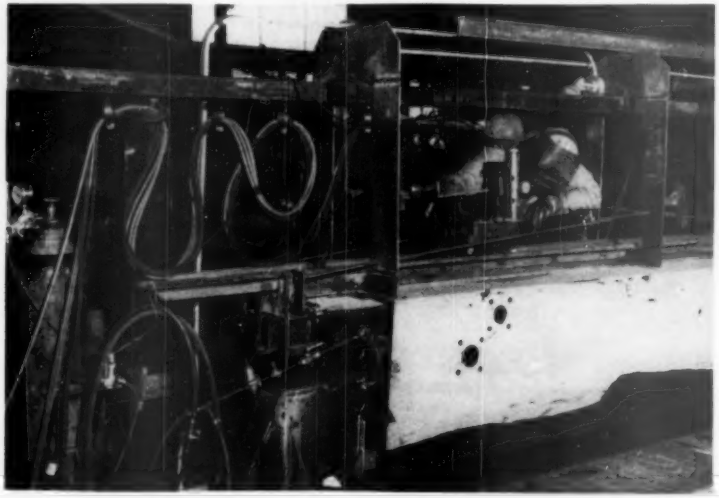


Fig. 12 4 clamp jig for longitudinal seam in which clamps are fixed and backup movable by means of air pressure admitted to hose underneath backup

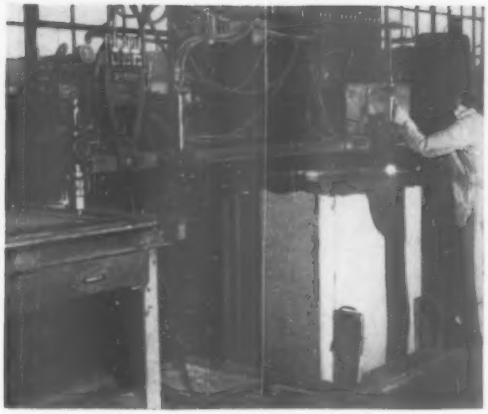


Fig. 13 Welding heads in tanks shown Fig. 12

Tank held in floor jig and arc travel controlled by magnetic tracer on oxygraph

ample of this phase of the problem is pictured in Fig. 11 which shows a jig designed for the production of welded aluminum chair legs. Welding in this instance is performed with the balanced a.-c. type of equipment—shielding gas is helium. Welding speed on this is 75 in. per minute with a welding current of 150 amp.; metal thickness is about 0.050 in. It is interesting to note that when this job was performed with the same equipment but using argon at 180 amp., the welding speed was only 60 in. per minute. Gas flows were the same for argon and helium.

The clamping arrangement is made of two solid blocks into which are machined appropriate contours for holding the irregular shape of the chair leg. These blocks are brought together under pressure after the stamped form has been inserted. Following this a shaped mandrel is inserted and held on the interior of the leg. This mandrel serves as backup for the welding operation. Note that the effect of a grooved backup is secured by flattening the corner of the mandrel under the weld. Closing of the block jig and advance of the mandrel are controlled by air cylinders. Incorporated in the jig structure is a track for the movement of the Radiagraph carrying the machine heliweld holder.

An interesting example for jigging long, straight, butt joints in stainless-steel commercial dish-washing units

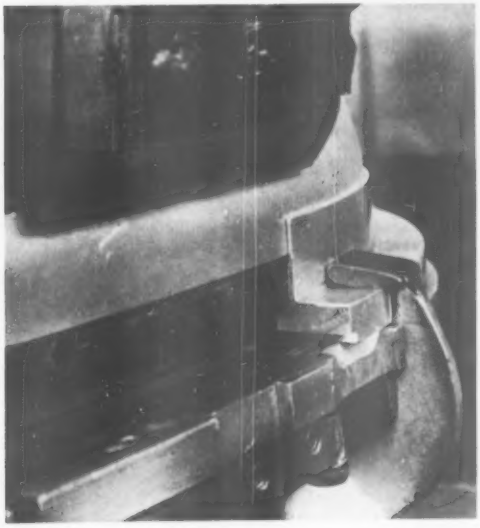


Fig. 14 Joint employed on 52S aluminum wing-tip tanks

Fig. 15 Jig for aligning and holding parts when inserting well in wing-tip tanks

is pictured in Figs. 12 and 13. These seams are welded with semiautomatic equipment using helium as the shielding gas and d.-c., straight polarity. The clamp bars in this jig are held fixed and reinforced and trussed for rigidity. It is the backup element in this jig which is movable. In fact, the backup bar is mounted above an asbestos hose to which is admitted compressed air. After the sheets are set and aligned, air is admitted to the hose forcing the backup against the root of the weld. Perhaps even more interesting is the skillful adaptation of an Oxygraph cutting machine for welding the ends into these tanks as may be seen in Fig. 13. The joint here is a corner joint with the horizontal or upper member overlapping, but flush with the outer edge of the vertical sheets. Again welding is performed

with direct current, straight polarity and helium, and the machine heliweld holder mounted on the torch bar; the path of the arc is guided by the magnetic tracing device and cam visible at the left. The straight seams are welded at 60 ipm., using 130 amp., d. c., straight polarity and 12 cfh. of helium. The edge joints on the ends are tack welded in place with a $^{3}/_{32}$-in. carbon electrode in a heliweld holder following which they are welded at 35 ipm. using 130 amp., direct current, straight polarity and 12 cfh. of helium.

The tooling for the large-scale production of aluminum wing tip fuel tanks for air planes represents one of the most complicated and ingenious assemblies yet devised. The joint involved here is a lap joint between the irregular-shaped stamping of 52S sheet aluminum and an extruded flange section of the same composition. Figure 14 shows a close-up of the joint. The weld is made at the upper edge of the extrusion to the sheet. These wing-tip tanks are about 8 ft. long and roughly in the shape of a cigar. Near the middle of the tank is an inverted well to accommodate the wing tip. This is visible in Fig. 15 which actually shows the line-up jig for inserting the well, and holding the parts to permit of making the edge weld.

Welding is performed with the balanced a.-c. type of equipment using argon shielding gas. The fillet weld is made in the horizontal position by a torch traversed by mechanical means. The arrangement for this is pictured in Fig. 16. The Radiagraph has been modified so that the drive wheel contacts a continuous chain incorporated in the jig structure at about the line of the weld. In so doing, the machine is caused to travel at the same speed as the welding arc avoiding complications at points of change of direction. It is important to note here that this is a horizontal fillet weld made with a semiautomatic setup.

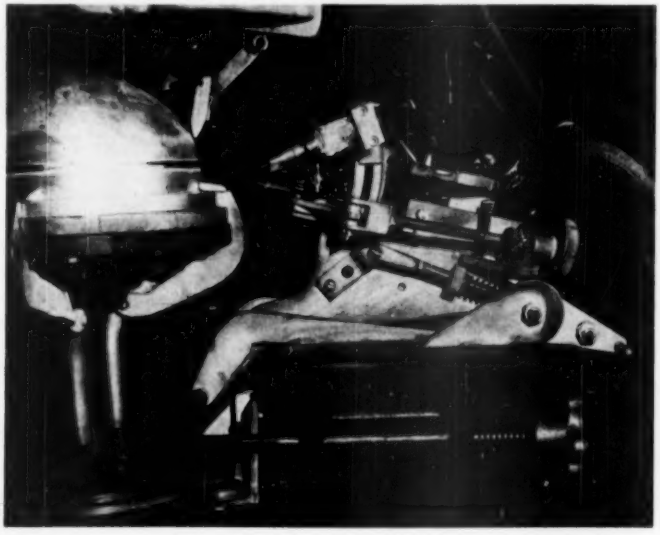


Fig. 16 Mounting of hand holder on radiagraph for welding; also propelling of machine by means of chain on jig and sprocket on machine

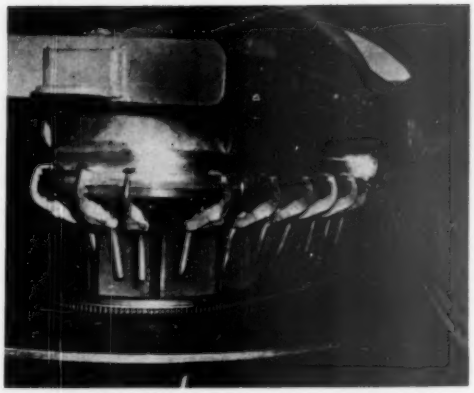


Fig. 17 Clamping arrangements for wing-tip tanks

Toggle clamps for extruded flange and segmented bars for stamping

This job is an excellent example of the use of segmented clamp bars which in this case are dictated by the irregular contour. These segmented clamp bars are shown in Fig. 17 but may also be seen in Fig. 16 and in close detail in Fig. 14. Note also the hold-down toggle clamps which not only fix the position of the extruded shape with respect to the base of the jig but also provide for a certain amount of lateral pressure to force the up-standing leg against the stamping. These hold-down clamps may be seen in Figs. 14, 16 and 17.

The backup design for this jig is illustrated in Fig. 18 which shows the movable section at one end and the locking arrangement to force the backup into intimate contact with various elements of the assembly. These backup sections are made of nonmagnetic copper-base alloy and are water cooled.

Figure 19 shows the jig employed for installing the wing tip well on the tank section. Actually, this is the same jig shown in Fig. 15 but with the workpieces removed. Note again the use of chain track for guiding the Radiagraph around the weld joint.

The specific jig designs, thus far studied, have all been employed in various applications of the inert gas-tungsten arc-welding process. Inert gas-metal arc welding with a continuously fed consuming electrode imposes other different requirements. While this new process is acceptable for welding in all positions, it must be appreciated that, in common with all welding processes, welding in the flat position proceeds at the fastest rates and should, therefore, be used for economical reasons.

One of the principal fields of use for

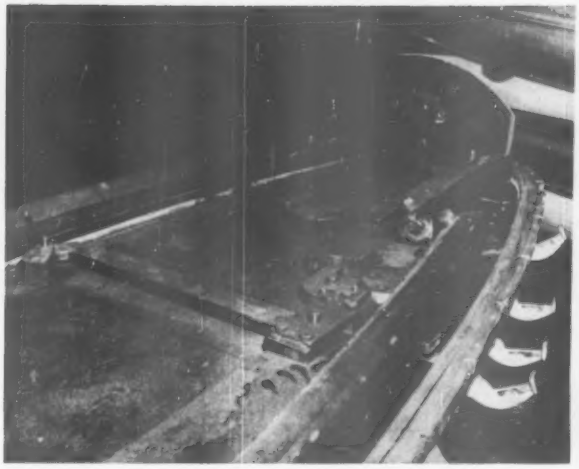


Fig. 18 Arrangement of nonmagnetic, copper alloy backup with locking section, backup water cooled

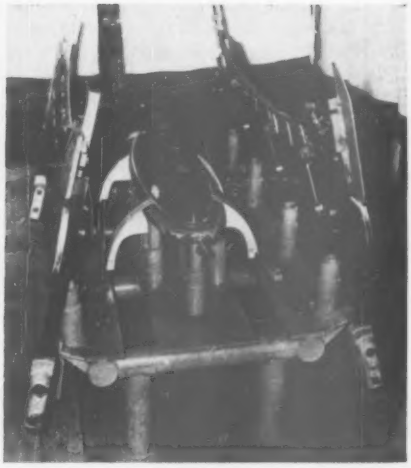


Fig. 19 An open view of the weld jig, Fig. 15

the Aircomatic Process is for the welding of aluminum. Figure 20 illustrates an ingenious jig employed in the assembly of large aluminum tanks fabricated of 61ST6 alloy. The function of this jig is to provide for downhand welding. Here the several subassemblies of the tank have been brought together in the trunion mounted rotating jig. The various internal stiffeners in the tank are thus welded to the tank shell in the flat position by the simple expedient of turning the assembly about its axis.

The fabrication of a high-tension bus bar supporting structure of aluminum is pictured in Figs. 21 through

Fig. 20 Rotating assembly jig for welding aluminum tanks

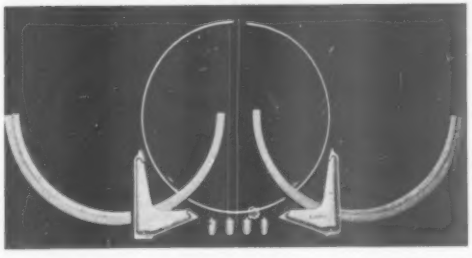


Fig. 21 Component parts of 61S aluminum used in fabrication of high-tension bus support

Fig. 22 Welded bus support

26. The welding of several components illustrated in Fig. 21 is accomplished with the Aircomatic Process and the end results may be seen in Fig. 22. To accomplish this end result, several novel jigging fixtures and adaptations of standard weld positioners are necessary.

In Fig. 23 is shown the assembly for tack welding of the central cylindrical element together with the two semicircular channel sections. In order to provide the necessary clamping forces, observe the extensive use of toggle clamps and even "C" clamps. The butt weld in the cylindrical element is made in three passes from the inside while the assembly is mounted in the jig. In a similar manner the butt weld adjoining the semicircular channel sections are also made in this jig.

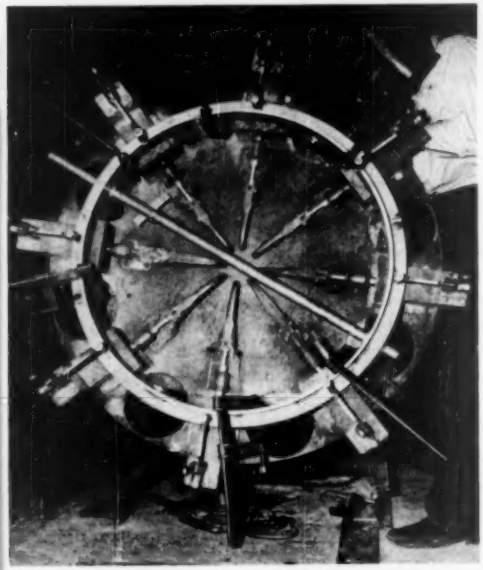


Fig. 23 Assembly and tacking jig for bus support, mounted on a positioner

The joining of the channel sections to the central cylinder by means of continuous fillet welds is illustrated in Fig. 24. Here the assembly has been mounted on a standard welding positioner so that it may be rotated under the Aircomatic Gun. This in itself is a novel arrangement since the gun, which is normally a hand tool has been provided with temporary mounting to provide mechanized welding as may be seen in Fig. 25. The final operation in this assembly is to weld the cast-aluminum legs to the ring section as may be seen in Fig. 26. This use of the inert gas-metal arc-welding process with the continuously fed consuming electrode provides a saving of one-third in gas consumption alone, over the previously used method. Obviously, the use of jigs and fixtures contribute to the efficient handling of the entire welding assembly.

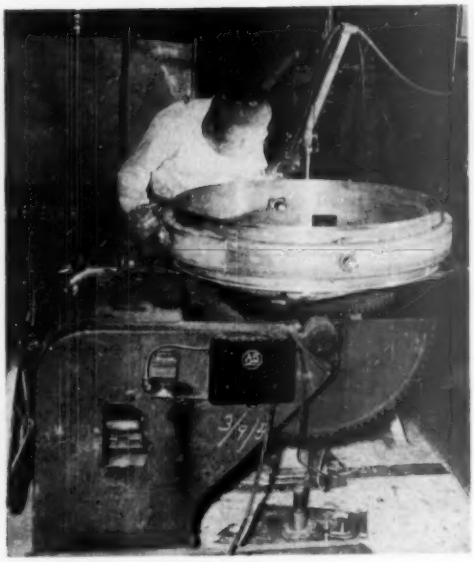


Fig. 24 Making continuous fillet welds joining cylindrical sections, work mounted on positioner

The inert gas-tungsten arc-welding processes inherently offer many attractive advantages for production welding, particularly in the hard-to-weld metals. To achieve maximum use of these advantages, it is neces-

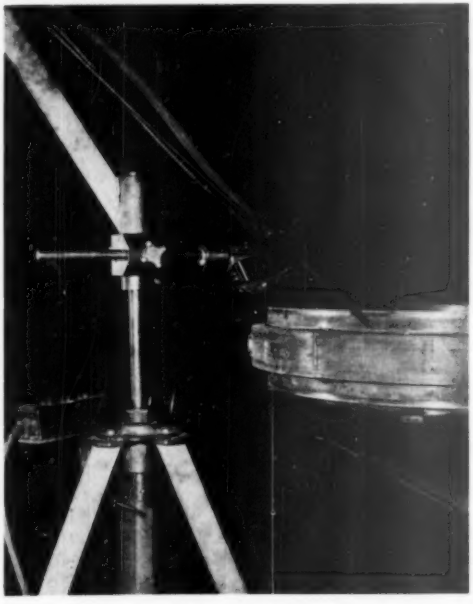


Fig. 25 Mounting of aircomatic hand gun to provide mechanized welding

Fig. 26 Supporting brackets manually welded to ring

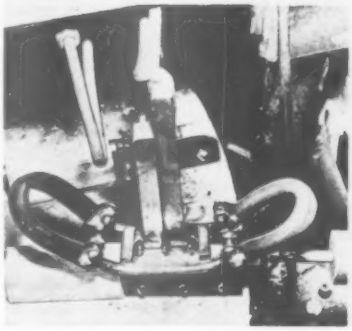
sary to design and utilize, intelligently, jigs and fixtures to fit the process and the product on hand. Certainly, the importance of designing jigs and fixtures suitable for the process is amply demonstrated both in the principles and the cases herein sighted. These examples are offered not so much with the thought that they are the ultimate, but that they represent a rational approach to the problem. It is still patent that two designers of jigs and fixtures presented with the same fundamental problem, would each arrive at different solutions to the problem.

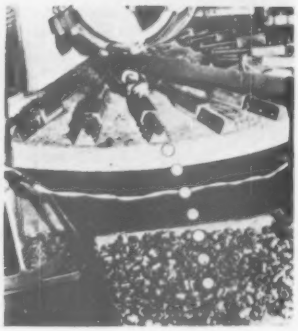
Acknowledgments

The authors wish to acknowledge, gratefully, the cooperation of Chief Welding Engineer, T. Imholz, Republic Aviation Corp., in securing the data and pictures of the welded aluminum wing tip tanks. They also wish to acknowledge the assistance of Welding Superintendent, J. Hilewick, Railway and Industrial Eng. Co., for the data and pictures on the aluminum bus-bar support.

Mechanizing Brazing Operations

THE trend in silver alloy brazing, where volume production is involved, is toward almost complete mechanization by means of heating equipment with indexing tables or conveyor lines, by parts positioning through jigging arrangements and by preplacing the silver brazing alloy in wire ring or other prefabricated form. In the example shown here, stamped steel "roll backs" for door locks are fluxed and assembled by the operator with a tiny square of Easy-Flo placed between the teeth of the roll backs. After placing three assemblies in each jig, the machine takes over. First, an air cylinder plunger shoots forward, clamping the assemblies in the jig. A movable induction heating coil then drops automatically into position for a 9-second application of heat. The coil goes up and the assemblies ride two stations while the brazing alloy sets. Finally, a second air cylinder plunger ejects the finished assemblies from the indexing table into a shipping crate. With this mechanical setup a saving of one-third was lopped off the cost of producing 500,000 roll backs. Production can be doubled by adding a second heating station and another operator to the present indexing table.





PRACTICAL WELDER AND DESIGNER

Hints for White Metal Welding

by E. V. Olson

WHITE metal castings are used on automobiles, household articles such as washing machines and vacuum cleaners, industrial parts and many types of brackets. Since they are often difficult to replace when they break or wear out, welding these die castings can be a profitable business for the welding shop.

GETTING READY TO WELD

The first step in getting ready to weld a white metal casting is to make several tools from steel welding rod as shown in Fig. 1. These are useful for breaking down oxide coatings, to form the plastic metal and to transmit heat from the flame to the casting when thin sections are welded.

The next step is to choose a welding rod. Your welding supply jobber has commercial white metal welding rod that will help make a good repair. The same rod can be used for most white metal castings. For most jobs, rod should be $^3/_{16}$ in. or less in diameter. For small, thin-walled castings, $^1/_8$-in. rod is recommended.

Cleaning both the rod and the part to be welded is

Fig. 1 These tools, formed from welding rod, are useful for breaking down oxides during welding and for smoothing and shaping the metal

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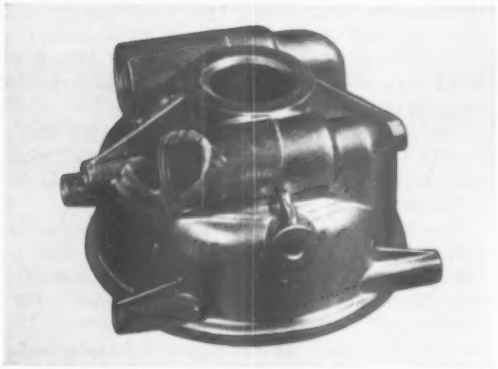


Fig. 2 Clean the weld area to remove grease, oxides and plated coatings

Fig. 3 Insert a carbon rod in the casting to support the weld metal you deposit

important. All grease, oil or dirt should be removed. It is also important to remove any plating or oxide coating from the casting before welding. White metal melts at about 800° F. but the chromium plating or oxide coating melts at about 2100° F. This means that you must file off any plating or oxide coating for about $^1/_4$ in. on both sides of the break. Or, if you are rebuilding a worn surface, you must clean off the surface you want to rebuild.

Clean the welding rod, too. Use a "vixen" file to remove the oxide coating before you begin welding. If the rod is not cleaned, the oxide film will get into the puddle and interfere with the welding.

Dirt and grease that might interfere with the welding also should be removed. In order to assure a thoroughly clean surface, paint the area to be welded with aluminum flux. Leave it on for a few minutes, then wash it off with water.

BUILDING-UP PARTS

To weld a broken casting, like the one shown in Fig. 2, first clean around the broken edge as explained above. Then insert a carbon rod into the casting as shown in Fig. 3. The carbon rod will support the weld metal and will reduce the amount of finishing you will have to do.

Bricks, carbon paste, rod, plate and wet asbestos are valuable for holding parts in position and for furnishing the necessary support. Wet asbestos paper is especially useful when you weld castings with thick

Fig. 5 Build up the weld area about $^1/_{16}$ to $^1/_8$ in. higher than the adjacent surface

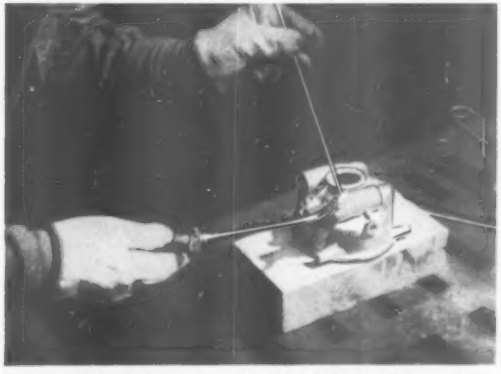


Fig. 4 Add welding rod to the edge of the break to replace the missing piece

Fig. 6 After the weld cools, shape the part and file off the excess metal

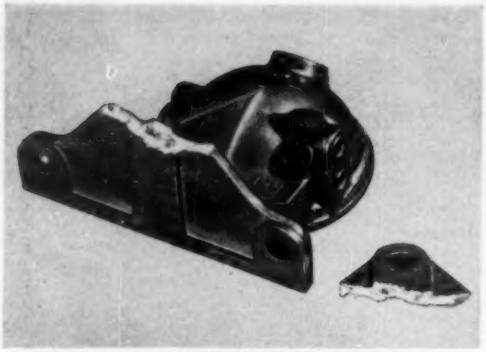


Fig. 7 On this job, too, a good weld depends upon thorough cleaning of the rod and the part

and thin sections. Although only the thick section of the casting may have to be welded, heat will be transmitted to the thinner section and it may collapse. By packing wet asbestos paper around the thinner section you can keep it from becoming too hot.

PREHEAT CASTING SLIGHTLY

Adjust the blowpipe to a slightly excess acetylene flame, then play the outer envelope of the flame all over the casting. Hold the flame on the surface of the break for a few seconds, then move it over the entire casting again. White metal does not change color when heated, but you can tell when to start welding by watching the break. When fine beads or droplets appear on the surface at the break, the casting is ready to weld.

Do not heat the casting too much. If it gets too much heat, beads or droplets will appear over the entire casting and there is a good chance that it will collapse.

BEGIN WELDING

Focus the flame on the surface of the break. At the same time, place the end of a cleaned, white metal welding rod in the flame. When the metal at the break becomes mushy, add molten welding rod, as shown in Fig. 4. Then move the flame away. By withdrawing the flame for short intervals, the metal can be kept under easy control.

When you deposit a little rod, shape and smooth the plastic metal with the spatula-shaped tool you made. This will reduce the amount of finishing you will have to do. Use the pointed tools to break down any oxides that may have formed and to remove any impurities from the weld metal.

Build up the weld metal about $^1/_{16}$ to $^1/_8$ in. higher than the adjacent surface as shown in Fig. 5. Then file the excess metal off when the weld has cooled. The finished part is shown in Fig. 6.

WELDING BROKEN PARTS

To weld a small casting, like the one shown in Fig. 7, first clean the broken edges. For most jobs, the next step is to bevel the edges to be joined. However, if you bevel the bracket shown here, it will be difficult to match the parts exactly. So for this job, it is best to line the parts up first, then melt out a vee.

Line the parts up on firebrick so that they match exactly. Support the larger part with a brick, then make tack welds at each end of the break to hold the parts together, see Fig. 8.

Now you will want to scrape out a vee across the break. Preheat the casting slightly. From time to time, play the flame along the break so it is heated more than the rest of the casting. When beads appear on the surface of the break, begin scraping out the vee. Use the spatula-shaped tool and scrape the mushy metal away along the break. Be careful not to melt out the tack welds. Scrape the metal away carefully, until you have a vee slightly deeper than $^1/_2$ the thickness of the metal.

WELD ACROSS THE BREAK

Next, make the weld. Begin at the center of the bracket, and add rod to the mushy metal from the bottom and sides of the vee. Work toward one of the tack welds. When you reach the tack weld, go back to the center of the vee and work toward the other end. Build the weld $^1/_8$ in. higher than the adjacent surface.

TURN PART OVER TO FINISH WELD

When the weld cools, turn the part over. Adjust the bricks so that the break is on the horizontal. Place some wet asbestos paper under the weld you must make, and see that the work is adequately supported to prevent sagging as the second side is welded.

Now play the flame along the break. When the metal becomes mushy, use the spatula-shaped tool to scrape out a vee on this side. Scrape the metal away until you reach the weld metal deposited on the outer side, see Fig. 9.

After you scrape out the vee, make the weld as you

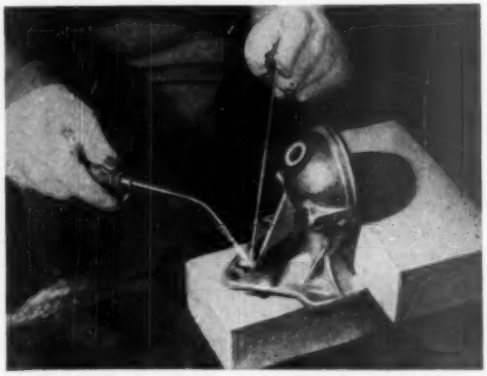


Fig. 8 Tack welds at each end hold the two pieces

did before. Add rod to the metal in the vee. Use the spatula to shape the weld metal and break down any oxides that form. When specks of dirt appear on the puddle, skim them off the surface with the pointed tool. Build up the weld about 1/8 in. higher than the nearby surfaces. After the weld has cooled, file off the excess metal.

WELDING THIN SECTIONS

When you weld extremely thin sections, the spatula or one of the other tools can be used to transmit heat from the flame to the work. If the flame is played directly onto the thin casting the metal may collapse quickly. To prevent this, after the casting has been preheated slightly, the flame can be directed against the spatula about an inch above the end. When the end of the spatula is touched to the casting, heat will be transmitted to melt only the metal in the break.

Fig. 9 Use the spatula to scrape out a vee

Fig. 10 Finish the weld by removing the excess metal with a coarse file

WATCH THESE POINTS

Remember to remove the hard oxide, nickel or chromium plating, and grease from parts before you weld. Many easy jobs can be ruined unless the oxide or plating is filed off. Be sure to remove the oxide film from the welding rod as well.

Proper ventilation is important so that you do not inhale fumes during welding. Some parts, such as washing machine gyrators, may spall when heated. Protect your face, arms, and hands against the tiny pieces of white metal which fly off the gyrator.

Before you try your hand at doing your first white metal welding, practice on scrap parts. This will give you a chance to try flame adjustments, preheating, moving the welding rod and use of the tools. It will also help you recognize the change in appearance of the white metal as it passes from cold to molten state.

A New Method of Brazing and Soldering

◗ *Costs greatly reduced and efficiency increased*

by Charles Boyden, Sr.

A NEW method of brazing and soldering has recently been developed which is attracting a great deal of attention from shops where brazing or soldering is a part of their production applications. It was primarily developed to be used in connection with a suitable conveyor system, and, with such a setup, there is not only a great increase in speed but, in addition, a large saving in the materials used and a much cleaner and neater job.

The brazing or soldering is done with a so-called "Gun" which is used to feed the brazing or soldering wire at some fixed speed which synchronizes with the speed of the workpiece being processed. The speed of the wire as it passes through the gun can be varied to meet the requirements at hand; but, once adjusted to the required speed, maintains that speed indefinitely, and brazing or soldering becomes a continuous operation.

Engineering Department, Metallizing Company of America, Chicago, Ill.

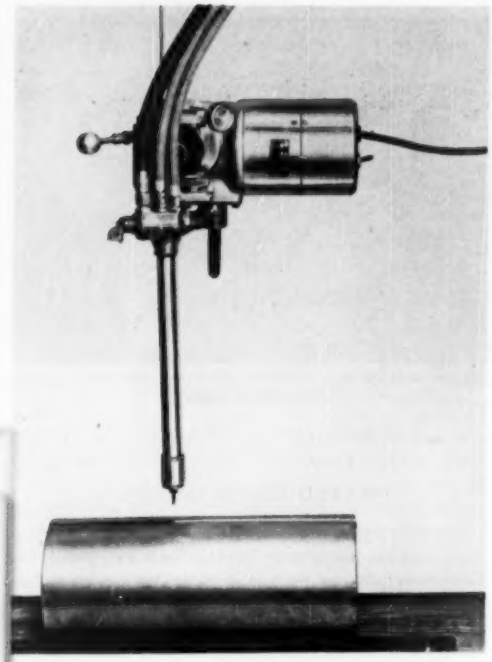


Figure 1

The "Gun" is a self-contained unit which has been especially designed for use in connection with the applications referred to. It is powered with a constant speed-induction motor to insure ample power and unvarying speed in operation. The unit can be started or stopped instantly, will feed the wire continuously or intermittently as desired and once put in operation it is practically automatic in performance. For melting the brazing or soldering wires, any of the combustible gases can be used.

As a rule, the Gun remains in a fixed position during the brazing or soldering operation, but in some cases the Gun moves and the work is stationary. In one installation it was found advisable to have the work and the Gun move together. It all depends on the nature of the workpiece and what is to be accomplished.

BRAZING

When set up for brazing, the Gun is usually mounted over the workpiece so the work will pass along under the Gun. The tube that guides the brazing wire is set in a vertical position as shown in the accompanying illustration. The end of the brazing tip is about $1^1/_4$ inches away from the surface to be brazed and remains fixed in that position.

For brazing, it has been found that natural gas and oxygen give splendid results. Fairly high gas pressures are used at the regulator to give accurate regulation, but small metering holes are used between the regulators and brazing tip so as to slow down the gas velocity at the tip. A fluxing gas is introduced into the natural gas line, and phos-copper wire is used for brazing.

The speed at which a seam can be brazed will depend upon the amount of copper required to fill the seam, the diameter of the wire used, and the gage and material being worked on. In practice, it has been found that seams can be brazed at the rate of 60 to 120 lineal in. per minute.

The brazing operation is simplicity itself. The brazing wire is fed into the flame just fast enough so it falls in small drops and, these drops being enclosed in the flame, remain molten and enter the seam in that condition. Inasmuch as the heat and the brazing metal are confined and applied directly into the seam, it is obvious there is a minimum of loss both as to the gas and wire used. The brazing is done so rapidly there is little heat dissipation over the surface of the work.

In some cases it is necessary to use a small preheating flame which should impinge on the work about an inch ahead of the brazing flame. This is used when it is desirable to speed up the process or when brazing heavier gage material. As a rule, no preheat is necessary when the brazing speed is less than 60 in. per minute.

When brazing thin or otherwise fragile sections, provisions should be made to cool the work immediately behind the brazing flame to guard against a spread of heat which might cause warpage of the material being brazed. This can be done by using an air jet which should strike the brazed surface 1 or 2 in. back of the brazing jet. Another method of cooling which has given good results is two very fine streams of water which are allowed to strike at each edge of the brazed seam, about 1 or 2 in. behind the brazing flame.

The technique used in brazing also applies to silver soldering. If anything, silver soldering is a little faster.

LEAD BASE SOLDERING

For soldering with any of the lead-base solders, the production setup is quite similar to the one used for brazing. The work travels along under the Gun, on the conveyor system, at a speed that synchronizes with the correct amount of solder which is allowed to drip into the seam to give a perfect solder job. The object to be soldered is placed on the conveyor in such a position that the seam is at the highest point so gravity and capillary action can be utilized in filling the seam. A speed of 50 lineal ft. of soldered seam per minute is easily attainable with an efficient conveyor.

With the soldering installation, foreburners and afterburners are used to heat the work sufficiently so the solder will flow. The tube which guides the wire solder is set at an angle of 45° to the work so the flame does not strike directly on the surface as in brazing. This is principally because of the thin sections found in cans or other articles which would adapt themselves to this type of high-speed production soldering.

For lead-base soldering, natural gas at low pressures

is entirely satisfactory, and any of the lead tin alloys in wire from $^1/_{16}$ to $^3/_{16}$ in. diameter can be used for this kind of work.

There are several advantages in connection with this method of production soldering. It is much faster, makes a cleaner and better looking job, the solder is applied only to the immediate area of the seam and there is a saving of solder which, in some cases, amounts to as much as 75%. In fact, the soldering is so rapid, that the full capacity of the Gun cannot always be utilized and it is often necessary to slow it down to correspond with conventional conveyor and manufacturing speeds.

Welding vs. the Future Bridge Engineer

A brief thought-provoking article on how to design and build welded bridges that will be better and more economical

by Dr. Alois Cibulka

THE progressive automotive engineer produced better cars for less and less as the time rolled on and the structural engineer should follow suite.

He could build today better bridges from the sheer waste of material and labor which is unavoidable with present construction methods. Welding process makes it possible and the scarcity of materials may prove to be a real blessing in disguise by forcing him out of the rut of conventional thinking.

In Civil Engineering, January 1949 (publication of A.S.C.E.) there is an immensely interesting article by Dr. J. J. Polivka, of University of California, describing the construction of a large span-concrete arch bridge built recently in Europe. It will pay good dividends to any engineer to read it.

For comparison purposes similar bridges of 500-ft. spans were designed by the writer, and the results needing no comments are shown on the drawings.

When also the bridge super structures are taken into account the concrete bridge is ten times heavier and needs ten times as much lumber than the welded one. The carpenter work difference is enormous. Another example are the State of Texas Riveted Highway Bridges. They require four times as much steel as the welded Tied-Arch Types which are much better looking, need less painting and shorter time to build.

For compression the timber is the best, most economical material available today; logically it should be used for columns or arches as much as practical and made to last forever by protecting it against the elements of nature by sealing it hermetically in welded metallic shells.

The technique of fabricating timber structures of large sizes, arches, trusses, glued, bolted, nailed, was highly developed in recent years and their strength proved beyond any doubt.

Metal and timber divide the loads proportionally to the moduli of elasticity. For steel $n = 20$; for aluminum $n = 7$.

With working stress of steel of 20,000 the corresponding stress in timber can reach only 1000 lb. per square inch, and therefore a low grade lumber can be used for the cores.

When high grade lumber of 2000 lb. is used the aluminum stress cannot exceed 14,000 lb. per square inch and therefore a relatively soft aluminum of good weldability is advantageous.

Aluminum weight is only one-third of that of steel; the timber core is twice as effective; the structure is lighter, needs no painting; all these advantages make aluminum more economical even if its price is 5 to 7 times higher than the steel.

Today the structural engineers are trying hard to adopt welding process to the rolled sections, which were intended for riveting only. This is wrong in principle and doubly wrong in practice.

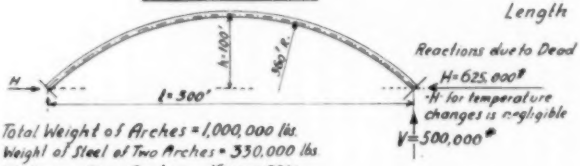
Details of welded connections look more like a nightmare than the work of a sane mind, and in spite of it sayings of 10 to 20% are claimed. Three to four times higher savings are within our reach and graceful long-span arch bridges to rival the suspension type are practical possibilities.

The horse-buggy was used for automobiles at the beginning, but look what happened since.

Dr. Alois Cibulka is with the Department of Engineering, University of Houston, Houston, Tex.

Comparative Highway Bridge Arches for similar Loadings.

Welded Arches



Length of Arch = 560 ft.

Reactions due to Dead Weight of Arches alone

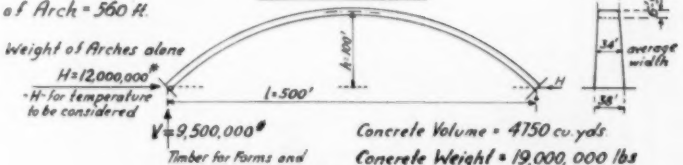
H = 625,000#

-H for temperature changes is negligible

V = 500,000#

Total Weight of Arches = 1,000,000 lbs.
Weight of Steel of Two Arches = 330,000 lbs.
Timber per Two Arches = 160,000 FBM.

Concrete Arch.



Timber for Forms and Centering = 1,200,000 FBM

Concrete Volume = 4750 cu. yds.
Concrete Weight = 19,000,000 lbs
Reinf. Steel Weight = 200,000 lbs.

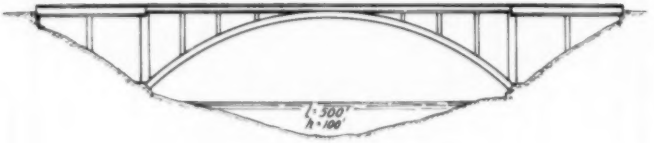
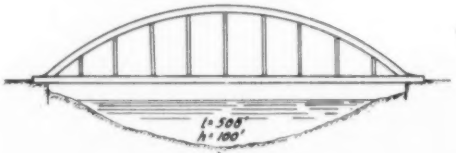
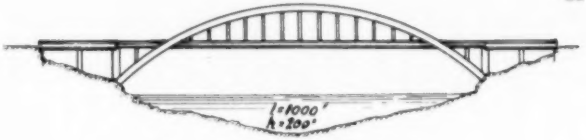


Figure 1





Texas State Riveted Highway Bridges. Year 1931

24' wide

Weight of Steel per Truss = 190,000 lbs
Painting Surface 3½ times larger

Comparative Welded Tied-Arch

Weight of Steel per Arch = 50,000 lbs.
Lumber per Arch = 6,000 FBM.
Welding approx 2000 ft. of ¼" weld

Typical Arch Detail

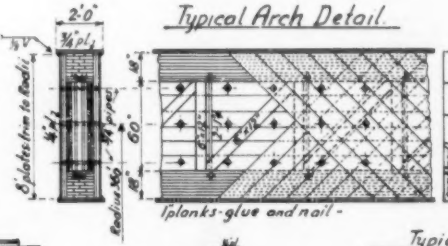

2'-0"
¾" pl.
5 plates 1½ to Radii
4½"
60"
68"
Radius 360'
Flanges
Web
Splices
Splices
Splices

Fig. 1 Place the nozzles in cleaning solution overnight

Fig. 2 Square up the flame end of the nozzle with emery cloth

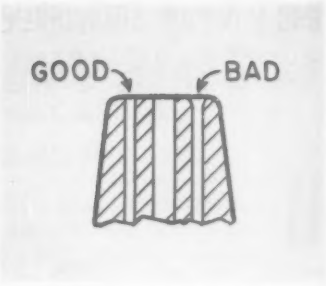


Fig. 3 Passageways should be clean, smooth and sharp

How to Clean Tips and Nozzles

For best results keep apparatus in good operating condition

by J. Villoresi

GOOD results as well as personal safety in welding and cutting depend, among other things, upon an accurate flame adjustment. You need a clean tip or nozzle to get the proper flame adjustment. Here are procedures for cleaning a cutting nozzle which is badly clogged with slag. Similar steps should be followed for cleaning a welding tip.

Prepare a solution of 20 parts of water and one part of a good nozzle cleaning compound that you can get from your welding supply jobber. Place the nozzle, with any others that need cleaning, overnight in this solution. In the morning, rinse the nozzles in clear water and allow them to dry.

Now square up the flame end of the nozzle by rubbing it on fine emery cloth, as shown in Fig. 2. Hold the nozzle perpendicular to the cloth and use long straight strokes. Be sure the flame end is square and free from scratches.

Passages must be clean, smooth and of the correct size. Bell-mouthed passageways will cause the flame to snap out when the blowpipe valves are closed, so rub the flame end of the nozzle on the emery cloth until the bell-mouthed condition disappears.

Next get out your tip cleaners. Start with a tip cleaner a size smaller than recommended in the blowpipe instruction booklet and work it up and down in the preheat and cutting-oxygen orifices. Do not twist the cleaner. When it slides freely change to the recommended size cleaner.

After cleaning, insert the nozzle in a blowpipe and light. Then examine the flame. The preheat flames should be the same size and shape, and the cutting-oxygen jet should be straight and symmetrical. A flame of this type will help insure a smooth cut.

J. Villoresi, The Linde Air Products Co., Newark, N. J.

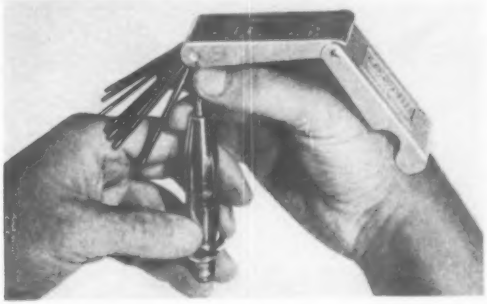


Fig. 4 Use tip cleaners to clean preheat and cutting-oxygen orifices

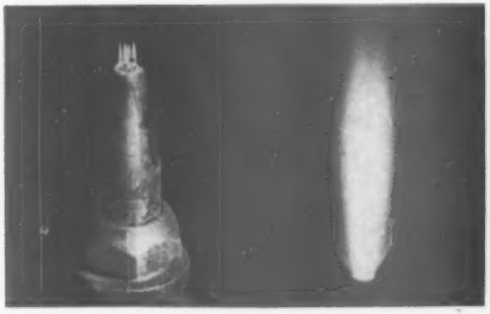


Fig. 5 A flame like this will help make a smooth cut

Don't Scrap Automobile Springs

by G. R. Clay

WELDING operators seldom cut up a broken automobile spring to sell as scrap—it is too valuable. The pieces of special steel that make up the spring are mighty useful in a welding shop. They can be used to replace parts or to make wood scrapers, chisels, punches and other tools. Here is how you can make hinges for heavy doors.

The curved main leaf has an eye at each end for the shackle connection. You need two springs to make a set of hinges. Cut the leaf about 9 in. from each end with your oxyacetylene cutting blowpipe. You are going to use these end pieces. But do not throw away the center piece. Save it to make other things. Now drill or cut three holes in each end piece for the screws or bolts. These holes should be cut as shown in the sketch. Two ordinary bolts complete the hinges. The bolts should be a good fit with the eyes so the doors will not sag.

G. R. Clay is with The Linde Air Products Co., Tulsa, Okla.

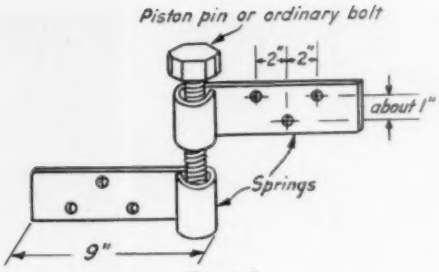


Figure 1

Hints for Making Corner Welds

by L. L. Kelly

THERE are several designs for making corner welds in sheet steel. One of them is the simple butt weld. Here are some hints for doing the job. You can use the same method for either braze-welding or fusion welding.

You do not have to bevel the edges of the steel. Use two C-clamps and a length of angle iron to line up the edges. They should almost touch and form a natural vee for welding.

L. L. Kelly is with The Linde Air Products Co., Atlanta, Ga.

When the weld is about 6 in. long make a tack weld about 1 1/2 in. from the open end. You will need two tack welds if the weld is 12 in. long—one about 1 1/2 in. from the end and the other about 7 in. from the end. After you make the tack welds remove the clamps and angle iron and position the corner so the vee is in the flat position, as shown in Fig. 3. Start the final weld at the open end and work toward the closed end. Remelt the tack weld when you come to it.

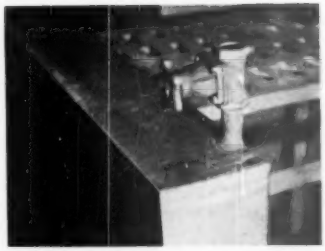


Fig. 4 Here the finished weld shows a smooth, even deposit of weld metal

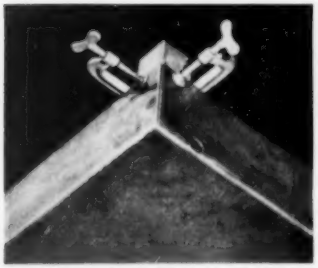


Fig. 1 Use C-clamps and angle iron to hold the edges in position

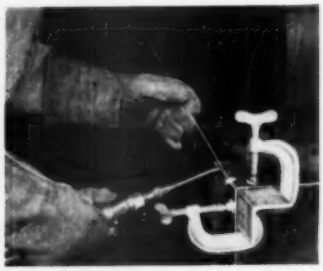


Fig. 2 Make a tack weld about 1 1/2 in. from the end

Fig. 3 Remove the clamps and weld from the open end to the corner

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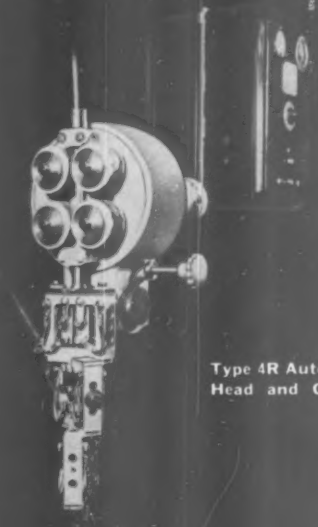
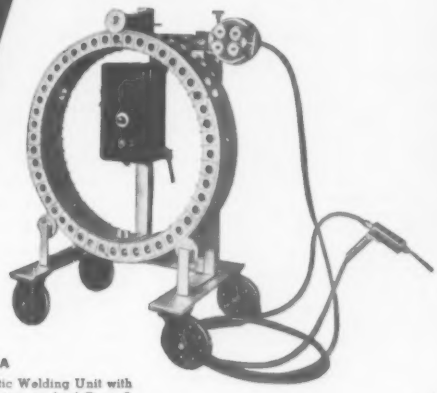


Type 4R Automatic Head and Control



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the AMERICAN WELDING SOCIETY

activities • related events

Executive Committee Meeting

A meeting of the Executive Committee of the AMERICAN WELDING SOCIETY was held in the Engineering Societies Building on June 7, 1950, with the following in attendance:

Members: O. B. J. Fraser, *Chairman*, D. Arnott, R. S. Donald, H. O. Hill, and C. H. Jennings.

By Invitation: H. R. Morrison.

A.W.S. Staff: J. G. Magrath and F. J. Mooney.

Member Absentees: T. B. Jefferson and H. W. Pierce.

Progress Report Rendered on the 1950 Convention Committee Activities

H. R. Morrison, Chairman of the Convention Committee, reported that the majority of the plans for the 1950 Annual Meeting are proceeding normally and successfully. He reported on the major items of interest concerning the SOCIETY'S Annual Meeting as follows:

Housing—A.W.S. has been allotted 900 rooms by the Hotel Sherman. The total number of rooms requested to date is well over 900.

Plant visit—plans for the inspection trip to Plant No. 2, Electro-Motive Division of G.M.C. are progressing in good order.

Registration fee—In accordance with previous action taken by the Board of Directors, plans are now being made to charge a registration fee at the 1950 Annual Meeting in the order of $1.00 to members and $2.00 to non-members.

It was also voted that "HAVE YOU REGISTERED?" signs be placed at the meeting room entrances but not for the Society to police the meeting rooms to check if all in attendance thereat have registered.

Booth at metals show—the Convention Committee at its meeting on May 3, 1950 voted not to request a booth at the 1950 Metals Show in view of the difficulty of securing sufficient personnel to man the booth throughout the week of the Society's Annual Meeting. The Executive Committee so approved of this action.

E. H. Ewertz Memorial Resolution

At a meeting of the Executive Committee of the SOCIETY on April 26, 1950, a three-man committee consisting of J. H. Deppeler, *Chairman*; D. Arnott and A. G. Oehler were appointed to prepare appropriate memorial resolution to be spread on the records of the SOCIETY and transmitted to E. H. Ewertz's family and company associates.

At this meeting, appropriate memorial resolution for the late Mr Ewertz, as prepared by this Special Committee, was confirmed and by vote of the Executive Committee the resolution was adopted for the records of the SOCIETY and transmittal to Mr. Ewertz' family and company associates.

A.W.S. Participation in Western Metal Congress

The Secretary reported that W. H. Eisenman, Secretary, American Society for Metals, extended invitation to the AMERICAN WELDING SOCIETY to participate in the Western Metal Congress to be held in Oakland, California during the period March 19 to 23, 1951. A.W.S participation in this program would be in the order of presenting a technical program as it has done in five previous Western meetings. The A.S.M. will guarantee A.W.S. a contribution of $750 toward the expenses of the meeting and in the event the show is very successful, then the A.W.S. will receive additional monetary remuneration in the amount of $250. It was pointed out that last year the A.W.S. Los Angeles Section had a very successful show which resulted in its receiving $1,000 toward the expenses of the meeting.

The Executive Committee, upon motion, duly seconded, accepted invitation as tendered by the A.S.M. to participate, through its west coast sections, in the Western Metal Congress to be held in Oakland, Calif., March 19 to 23rd. It also voted that this event should be publicized by suitable announcement in the SOCIETY'S JOURNAL.

Action Taken with Relation to Recommendations of the Technical Activities Committee

Recommendations of the Technical Activities Committee were considered at this meeting, resulting in the following actions being taken:

(1) The Executive Committee approved the appointment of D. C. Boltz, Metallizing Engineering Co., as A.W.S. representative to the Canadian Government Specifications Board Committee on Metallizing.

(2) The Executive Committee approved of proposed American Standard "Safety in Electric and Gas Welding and Cutting Operations" for presentation to the American Standards Association, Inc., for final approval and subsequent publication by the AMERICAN WELDING SOCIETY.

(3) The Executive Committee approved of proposed "Recommended Practices for Metallizing; Part 1A—Metallizing Shafts or Similar Objects and Part II—Metallizing—Safety Recommendations" for adoption and publication as a tentative standard of the AMERICAN WELDING SOCIETY.

(4) Recommendation of the T.A.C. relative to the reorganization of A.S.A. Sectional Committee C52—Electric Welding Apparatus—as submitted, met with the approval of the Executive Committee.

Appointment of a Three-Man Committee to Prepare Memorial Resolution for the Late A. E. Gaynor

The death of A. E. Gaynor was regrettably announced at this meeting.

The late Mr. Gaynor was instrumental in the formation of the A.W.S. New York Section as well as an active member on the SOCIETY'S Board of Directors. He served on the Executive Committee of the New York Section from its inception in 1920 through 1930. He was a member of the A.W.S. Board of Directors from 1926 through 1940 and during the years 1928–29, 1929–30, 1932–33 was senior vice-president on the Society's Board of Directors.

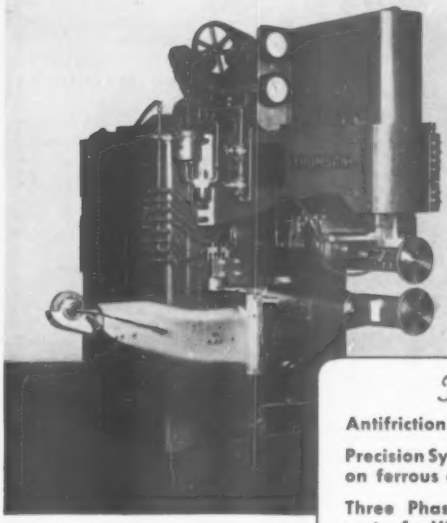
The Executive Committee appointed a three-man committee consisting of J. B. Tinnon, Chairman; C. Kandell and G. Schneider to prepare memorial resolution to be spread on the records of the Society and transmitted to Mr. Gaynor's family and company associates.

Action Regarding the Steel Information Center of the Netherlands Tour of the United States

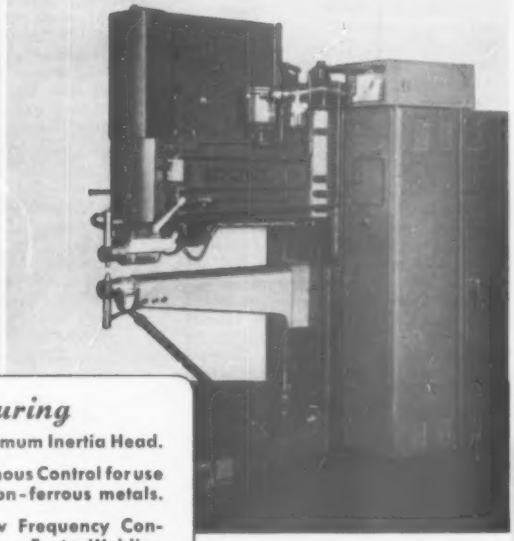
In a communication received from Prof. ir A. Roggeveen, Director, Steel Information Center of the Netherlands, Prof. Roggeveen advised that at the present time a team to study welding in general and electric welding in particular is being formed for the purpose of touring the United States in the near future. He stated that although the tour of this team is being conducted by the E.C.A., he would greatly appreciate any suggestions from the A.W.S. as to objects, institutions and factories that could be visited while here in the U. S.

After considerable deliberation, the Executive Committee was of the opinion that their needs could be better served by the welding manufacturing groups in the United States rather than by the SOCIETY. Accordingly, the Executive Committee directed the Secretary to suggest to Prof. Roggeveen that he contact the

SEAM WELDERS



SPOT WELDERS



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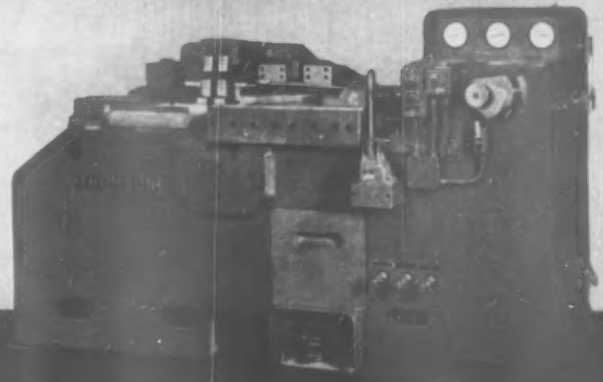

following groups if he has not already done so: R. L. Nims, Secretary, National Electrical Manufacturers Association, 155 E. 44th St., New York, 17, N. Y.; H. F. Reinhard, Secretary, International Acetylene Association, 30 E. 42nd St., New York 17, N. Y. and G. A. Fernley, Executive Secretary, Resistance Welder Manufacturers Association, 505 Arch St., Philadelphia 6, Pa.

Action Regarding Appointment of "Tellers of Nominations"

The Secretary reported that at the present time the National Nominating Committee is charged with the duty of canvassing and certifying results to the Secretary of all ballots cast for nomination to SOCIETY Officership. He felt that the President or Chairman of the National Nominating Committee should be empowered with the right to appoint "Tellers of Nominations," such to be chosen from Section in which National Headquarters is located and two adjoining Sections. The pattern to be employed could be similar to that employed for "Tellers of Election" as contained in Article IX, Section 7 of the SOCIETY'S By-Laws.

After reviewing this matter, the Executive Committee voted favorably to recommend to the Constitution and By-Laws Committee that the President appoint "Tellers of Nominations" and that the present by-laws be studied with suggestions for revisions to accomodate this change.

Membership Status Report for Nine-Month Period Ended May 31, 1950

The assistant Secretary reported that for the nine-month period Sept. 1, 1949—May 31, 1950, the SOCIETY reported a gain of 1185 members as against a loss of 1204 members, resulting in a net loss of 19 members. During the first six days of June, the SOCIETY enrolled four new members and three delinquent members remitted payment of dues.

A Membership Letter

August 31, 1950

To: Chairmen, Secretaries and Membership Chairmen of all A.W.S. Sections
District Vice-Presidents, District Chairmen and Members of National Membership Committee

Subject: *Membership—1950–51*

Gentlemen:

In my years of observing men and mankind, I have noticed that most persons thrive on good clean competition.

In planning the 1950–51 membership campaign for our SOCIETY, I have designed a campaign based upon competition within our SOCIETY.

Our program has four objectives:

1. New members.
2. Reinstatement of old members.
3. Maintaining membership by reactivation of delinquents.
4. Supporting company members and sustaining members.

For reaching these four objectives, the program calls for three contests:

1. Competition within the Sections.
2. Competition within the district between Sections.
3. Competition between the districts.

To support these three contests the program includes:

1. Competitition within the sections.
   - *a.* A section membership chairman to be appointed.
   - *b.* Membership chairman to select two "team captains."
   - *c.* Each "team captain" to head a team; one "red" and one "blue."
   - *d.* Team captains to choose their team members from the general membership, alternatively. The size of each team is determined by what is deemed necessary by each section for reaching its designated goal.
   - *e.* Score to be tabulated upon "dollar "value of membership.

2. Competition within the districts between sections
   - *a.* The district membership committee to pair off the section cities in their districts to compete against each other for the goal—the largest percentage gain in membership for the year 1950–51.

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b. The district vice-president and district membership committee chairmen and members to do all possible to stimulate friendly competitive rivalry.

3. Competition between the districts
   a. Districts to compete with each other percentage-wise on the same basis as outlined for section vs. section competition: (1) district 1 against district 4, (2) district 2 against district 5 and (3) districts 3, 6 and 7 with each other.
   b. The district membership committee chairman to organize his sections to assure his district bettering its current position.
   c. Chairmen of competing districts to maintain continued contact with each other as to respective standings, progress, increase, etc.

Our Society is offering two Bronze Plaques; one to be awarded to the Section achieving the largest gain in number of members, and one to the Section achieving the largest percentage gain in membership. Both Bronze Plaque Awards will be presented to the winning Sections at our 1951 Convention (Annual Meeting). Each winning Section will hold the Bronze Plaque one year. These Bronze Plaques are "revolving" Awards To be retained in any one Section, they must be won again the year following. Otherwise, they are awarded to the winning Section for that year.

Sincerely yours,

(Signed)
Henry C. Neitzel, *Chairman*
National Membership Committee
American Welding Society
c/o Whitehead & Kales Co.
58 Haltiner St.,
Detroit 18, Mich.

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Carbide
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ECONOMICAL
DEPENDABLE

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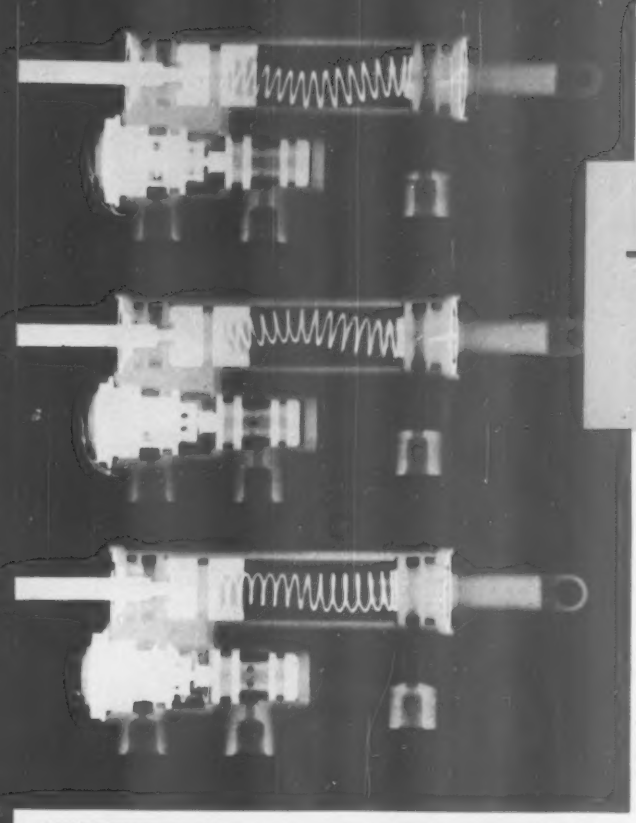
A Division of Air Reduction Co., Inc.

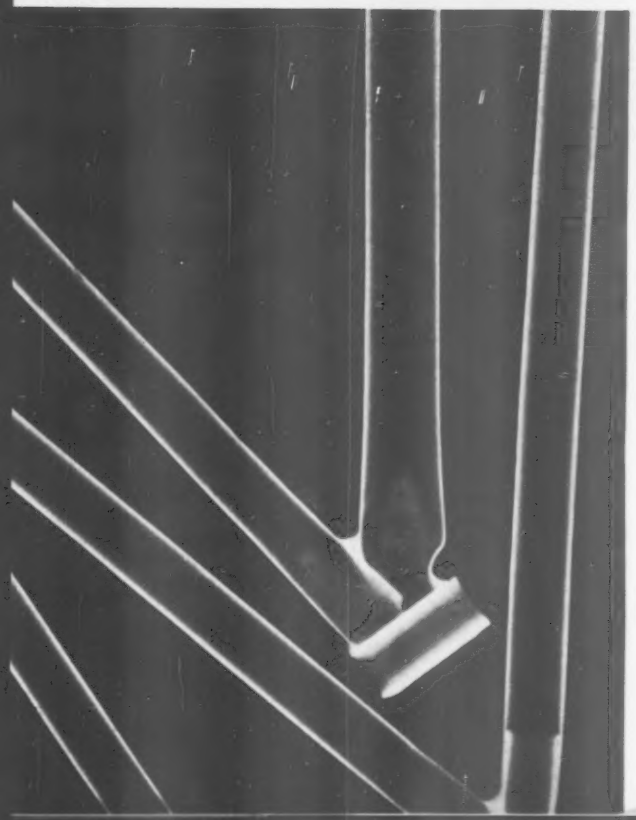


RADIOGRAPHY

goes beyond inspection of castings and welds

CHECKS ASSEMBLIES

Two of a group of hydraulic cylinders failed to function. Disassembly would have taken too long and involved breaking seals. Radiography compared the two with a good cylinder and revealed not only the compression springs rubbing on cylinder walls but also the absence of a second coil spring in the valve assemblies.



EXAMINES ENCLOSED SURFACES

Even though treated and sealed, these landing gear struts of an amphibian plane can develop internal corrosion and become weakened. Radiography alone can provide an examination of these internal surfaces. So the manufacturer has made it routine in the periodic inspection for service and safety of its amphibians.

Your x-ray dealer will gladly discuss the many ways radiography can aid your business by increasing foundry yield, checking welds and doing many other important and valuable non-destructive inspections.

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Radiography . . .

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WELDING CODES STANDARDS and SPECIFICATIONS

Are you fully informed on the latest welding standards available? Have you missed any of the earlier standards? This column is published as a regularly monthly feature of The Welding Journal to keep you abreast of AWS technical standards, which are universally recognized as the most authoritative source of welding information.

The list of publications shown below is only partial; it is changed from month to month.

Keep informed Read this column regularly.

B. TRAINING INSPECTION AND CONTROL

Training, Qualification and Inspection

B1.1-45 Inspection Handbook for Manual Metal-Arc Welding (Emergency Standard) $2.00

B2.1-45 Code of Minimum Requirements for Instruction of Welding Operators: Part A—Arc Welding of Steel 75c

B2.2-44T Code of Minimum Requirements for Instruction of Welding Operators: Part B-1—Oxy-Acetylene Welding of Steel Aircraft (Tentative) 75c

B3.0-41T Standard Qualification Procedure (Tentative) 50c

C. PROCESSES

Recommended Practices

C1.1-50 Recommended Practices for Resistance Welding $1.00

C1.2-42T Tentative Standards and Recommended Practices and Procedures for Spot Welding Aluminum Alloys (Emergency Standard) $1.00

C2.1-50T Recommended Practices for Metallizing: Part 1A—Metallizing Shaft or Similar Objects; Part II—Metallizing—Safety Recommendations Together 75c

NOTE: 25% discount to A and B members and 15% discount to C members of AWS on copies of any codes and standards listed above except starred items.

Send your orders, or requests for order forms containing complete list of AWS publications to:

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American Welding Society

33 West 39th Street

New York 18, N. Y.

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Have superior physical qualities — ideal for welding heavy sections that must withstand severe shock and abuse.

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- ***For chrome-moly steels*** (1¼ Cr., ½% Mo.) used in power piping ... *80LE.*
- ***For chrome-moly steels*** (2¼ Cr., 1% Mo.) used in power piping ... *90LE.*
- ***To match heat-treating properties of SAE 1040*** and like steels. Also for steel-castings repair... *P&H40C.*
- ***For welding high hardenable steels.*** Also steel castings repair... *AW2B.*
- ***For repair welding Grade C castings*** and steels of similar composition... *P&H#7.*
- ***Comparable to SAE 8630 steel...*** excellent heat-treating and flame-hardening characteristics... *90LH#2.*
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PERSONNEL

McCauley Joins Ohio State

Professor Roy B. McCauley, Jr., formerly a member of the Department of Metallurgical Engineering of the Illinois Institute of Technology, is now on the staff of

the Welding Engineering Department at Ohio State University in Columbus. Prof. McCauley is a member of the AMERICAN WELDING SOCIETY.

Wagner Honored

J. F. Wagner, Vice-President of the Burdett Oxygen Co. of Cleveland is selected as one of a four-man commission to go abroad to study new developments and operating methods of the compressed gas industry in Europe. This action was voted at the Annual Summer Meeting of the Independent Oxygen Manufacturers

Association, held in Banff, Canada. "The methods now being used in the production of oxygen and other gases were first discovered and developed in France and Germany," said Mr. Wagner, "so it is only natural that we start our studies at the source." Countries visited will include France, Germany, England, Italy, Switzerland, Belgium, Sweden and Denmark. This commission, which will represent all the independent oxygen manufacturers in the United States, Hawaii and Mexico will leave from New York City, on August 30th. Mr. Wagner, as past-president of the Independent Oxygen Manufacturers Association and chairman of the Atmospheric Gases and Hydrogen Committee of the Compressed Gas Association, will present the report of the commission's findings.

OBITUARY

Albert H. Guillot

When Albert H. Guillot died on Dec. 20, 1949, the AMERICAN WELDING SOCIETY suffered the loss of a loyal worker. His passing leaves a void, but also a treasury of memories of good work, good will and good deeds.

He leaves a wife, the former Emma Collins, a daughter, Nell Evelyn, and a son Albert Collins Guillot.

Albert Guillot was a credit to his profession and to his native city. He was born in New Orleans on Sept. 6, 1890. After completing high school, he continued his education with night school and correspondence courses in business administration, practical electricity and civil engineering.

His employment began in the services of J. F. Coleman, Consulting Engineer, in 1905, where he advanced from Rodman to Draftsman. In 1912, he became connected with the U. S. Engineers in New Orleans, where he advanced to Junior Engineer. In 1920, he became a member of the Roadway Department of the New Orleans Public Service Inc. and advanced to Principal Roadway Engineer, which position he held at his death—just a few days short of thirty years of continuous service with that company.

He served his country during World War I and had been active in American Legion affairs ever since. He was a member of the American Society of Civil Engineers, the Louisiana Engineering Society, the AMERICAN WELDING SOCIETY and served as Secretary and as President of the New Orleans Chapter, American Public Works Association. He was an active member of the Board of Directors of the Krewe of Nor.

Mr. Guillot represented the New Orleans Public Service, Inc., as a sustaining Member of the AMERICAN WELDING SOCIETY.

These men are working for you

J. D. Mattimore, intense, soft-spoken Chief Engineer, Tube Turns' Product Engineering and Research Division.

Meticulous, scholarly A. R. C. Markl, Chief Research Engineer, Product Engineering and Research Division.

Thorough, analytical Arthur McCutchan, Chief Product Engineer, Product Engineering and Research Division.

T. D. Bridge, quiet, studious Product Engineer, Product Engineering and Research Division.

LIKE MOST U. S. manufacturers, Tube Turns, Inc. is sincerely determined to bring its customers the finest products possible. Fulfillment of that purpose is largely the responsibility of its research and product engineers.

No general practitioners, these men are recognized piping authorities, possessing highly specialized knowledge and training in the field of piping engineering. Together, they represent a total of more than 100 years experience in the design and application of piping, fittings, and flanges for power, oil, chemical, marine, and general industrial service.

Aided and abetted by a corps of trained technicians, their efforts are consistently directed toward one never changing goal: *better welding fittings and flanges to serve you better!*

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If you are concerned with designing or erecting piping systems, you'll want to receive new "Piping Engineering" bulletins. Just write us on your business letterhead, giving name, title, address.

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NEWS OF THE INDUSTRY

Engineering Awards

Both honor and cold cash have been awarded to young engineers, in 23 different states and 40 different engineering schools, who were successful in the Lincoln Foundation's 1949–50 competition in its annual Engineering Undergraduate Award and Scholarship Program. A total of $5000 was awarded in 77 cash awards ranging from $1000 to $25. $1750 was given in scholarship funds to schools.

In honor of Gordon Dickson Orr, Jr., of Meriden, Conn., first award winner, the Rensselaer Polytechnic Institute of Troy, New York, has been granted $1000 in scholarship funds. Four scholarships will be established under Orr's name in the Department of Architecture in which Orr was enrolled when he prepared his award paper, "A Comparison of Framing in Welded Steel and Aluminum." Orr received an equal cash award of $1000.

The State University of Iowa, Iowa City, Ia., was given $500 in scholarship funds in honor of the second award winners, Francis Springer and Earle Compton, both of Iowa City, and enrolled in the Department of Mechanical Engineering. Springer and Compton divided the second cash award of $500 for their paper "Investigation of Some Practical Applications of the Low-Hydrogen Type Electrodes."

Jerry J. Watson of Seattle, Washington received third award of $250 and in his honor Oregon State College was granted funds of $250 for a scholarship in the Department of Engineering and Industrial Arts. Watson's paper was entitled, "A Study of Arc Weld Fabrication of Turret Tools for Turret Lathes."

The Engineering Undergraduate Award and Scholarship Program, open to all undergraduate engineers registered in engineering colleges, gives awards for papers on arc welded design, fabrication, maintenance or research. Scholarship funds are awarded to the schools in which the main award winners are enrolled. The program is sponsored annually by The James F. Lincoln Arc Welding Foundation of Cleveland, Ohio, to give undergraduate engineers an opportunity, not always available in regular school work, to do creative engineering on a level with that which they will be doing when employed by industry. The program encourages students to investigate and aid in the development of the science of arc welding and its industrial and agricultural application.

Dates for the current competition have been announced by the Foundation as June 1, 1950 to May 31, 1951. All engineering undergraduates are eligible to participate regardless of their graduation date during the year, so long as their entry is submitted while they are still registered as an undergraduate.

Papers entered in the 1949–50 competition were judged by a jury headed by Dr. E. E. Dreese, Chairman of the Department of Electrical Engineering, The Ohio State University. Serving on the jury were: Gilbert S. Schaller, Professor of Mechanical Engineering, University of Washington, Seattle, Wash.; Emmett B. Moore, Chairman, Department of Civil Engineering, State College of Washington, Pullman, Wash.; J. B. Wells, Professor of Structural Engineering, Stanford University, Stanford, Calif. and S. H. Graf, Professor of Mechanical Engineering, Oregon State College, Corvallis, Ore.

New Farm Welding Award Program for High School Students

Outstanding, experienced high school teachers from over 30 different states have formulated the rules of a new award program which this winter will give high school students studying vocational agriculture an unusual opportunity for national recognition and a chance to win a sizable award in cash. The program is a $7000 Arc Welding Award Program conducted by The James F. Lincoln Arc Welding Foundation of Cleveland, Ohio, especially for high school students in vocational agriculture.

For the best descriptions written by high school students of how arc welding was or could be used on a farm project, 100 cash awards totaling $5000 will be made. Awards totaling $2000 will be made to the schools in which the first 10 award winners are enrolled. The first award to students is $600 with a second award of $400. The other 98 awards range from $200 to $25. The first 10 awards are given in duplicate, sums equal to the student award going to to schools, which must be used by the school to improve a shop mechanics course.

The Program, aimed to encourage young farmers to study and think about the use of arc welding in farm operation, allows students to describe either a home project or a school project in which arc welding has or can be used.

Any vocational student enrolled in a high school and who is a member of a farm family actively engaged in farming can compete for awards by describing his maintenance, repair or construction farm project. A group of two or three boys can work together on a project and description if desired.

The jury for the program will be selected from teachers and experts in vocational education and will be directed by Dr. E. E. Dreese, Chairman of the Board of Trustees of the Foundation and Head of the Department of Electrical Engineering at The Ohio State University.

Illustrated booklet describing the program and suggesting typical projects can be obtained from the Foundation, Cleveland 1, Ohio.

National Welding Supply Association

As of September 11th, the new address of this Association is 1900 Arch St., Philadelphia 3, Pa. The new telephone number is LOcust 4-3484.

Milburn Moves to New Plant

Alexander Milburn, Inc., well-known manufacturer of oxyacetylene cutting and welding apparatus, has moved to new headquarters at 1231–45 Ridgely St., Baltimore 30, Md.

The Corporation's entire manufacturing and sales operations will be carried on from this address. The building includes 8000 sq. ft. of manufacturing area in which will be installed new and modern equipment of all types

Officers of the Corporation are: W. L. Lawrence, President; Emory Lawrence, Vice-President and L. H. Denton, Secretary.

Resistance Welder Manufacturers' Association

As of September 11th, the new address of this Association is 1900 Arch St., Philadelphia 3, Pa. The new telephone number is LOcust 4-3484.

Biggest All-Welded Gantry Crane

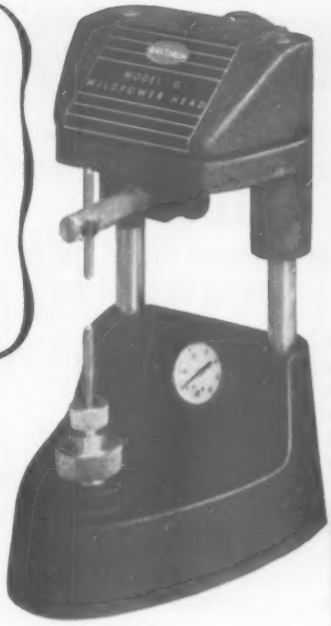
The 125-ton single-leg gantry crane installed at the National Tube Co., Lorain, Ohio, serving the Bessemer converters, is unusual, not only because it is the biggest of its type ever built, but also because of its shaftless bridge drive. The crane was built by the Cleveland Crane & Engineering Co., Wickliffe, Ohio.

Heretofore, bridge drives for all long span semigantries have employed motors, mounted on the bridge girders, arranged to drive the track wheels through line shafting, flexible couplings, bevel gears and universal joints. Most of these have been a source of maintenance difficulties to users.

The all-welded design of this crane, incorporating a welded box-section portal-type leg, provides maximum torsional rigidity to assure proper alignment of all parts and successful operation of the individual motor bridge drives. The hermetically sealed welded box sections used for both girders and leg, provide maximum resistance to corrosion, always a problem in the Bessemer area.

FOR HIGH SPEED PRECISION WELDING

of light gauge metals, wire and small parts



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New MODEL G WELDPOWER HEAD

A completely new welding head of patented design with precision operating features to match the improved precision control of new Raytheon Weldpower units.

CONSISTENT PRESSURE, predetermined and uniformly applied regardless of operator skill or other variables.

ACCURATE SETTING with continuous visual indication by air gauge. Settings can be recorded and readily duplicated at any time. Pressure range: 0.5 to 16 lbs.

INSTANT FOLLOW-UP with inertia virtually eliminated by a light, fast-acting air piston coupled to the lower electrode. Follow-up travel limited by micrometer adjustment.

ADAPTABLE for *series welding* by the addition of a second upper electrode or for *percussive welding* by simple accessories.

MORE COMPACT. Designed for minimum bench space plus maximum ease of work handling.

CONDENSER WELDPOWER

New CONTROL UNITS

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Model 60 Capacity: 63 watt-seconds

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Low-Temperature Welding, Brazing and Soldering Alloys and Fluxes

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- Save up to 80% on joint preparation
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- Save up to 90% on preheating
- Save up to 100% on distortion
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- Save up to 100% on burn-throughs

Many report savings up to 75% on Job Costs

Your own experience is the most convincing thing in the world. When you do it yourself you know you can do it again and again.

SAMPLER

The famous Doc Alloys Kit is a sampler of All-State products for torch application. It contains eleven types of All-State gas welding, brazing and soldering rods and appropriate fluxes, plus All-State galvanizing powder. There is everything, including ample supplies of silver solder, to weld anything—and, there's enough of everything to take care of a large number of jobs. Flux-coated as well as bare nickel-silver rods for brazing and build-up are furnished.

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For the opportunity to see for myself the inherent advantages of low-temperature joining, I'll pay your distributor $15 when you have him deliver to me one of your Doc Alloy Kits.

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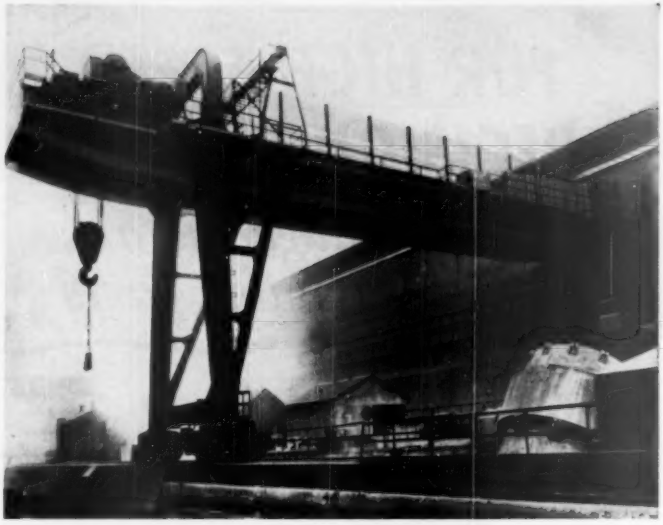


This big Cleveland semigantry crane, weighing 300 tons, serves four Bessemer converters, three of which are active. The fourth, visible at far right, is held for standby use. Each converter will produce 25 tons of steel in less than 20 min.

The bridge of the crane rides on eight equalizing-type two-wheel trucks, four of which are located at the gantry leg and four at the wall end of the crane girders. For each pair of trucks there is a direct connected individual motor drive, making four bridge-drive motors in all. No provision is made to electrically synchronize the motors.

Champion Appointment

The Champion Rivet Co. announces the appointment of Thos. J. Dempsey, Jr. as district manager of the Pittsburgh area. Mr. Dempsey was formerly connected with the National Bearing Division of The American Brake Shoe Co. He will be permanently located in Pittsburgh and will handle all of the Champion Rivet Co. products.

The Launching of M/L Esso Dispatch

The Esso Dispatch was launched at 10:30 A.M. Saturday, July 15th at the Madisonville shipyard of the Equitable Equipment Co., Inc., the builders.

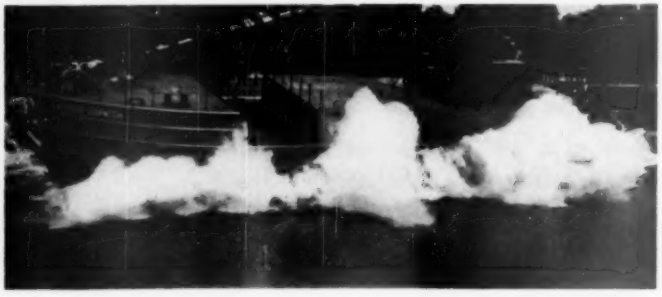
The Esso Dispatch is the first ship to be launched at the new yard of the Equitable Equipment Co., Inc. and is the 532nd hull turned out by the company's shipbuilding division.

The 300-ton (dead weight) welded vessel hit the water as company officials, workers and spectators watched Mrs. Balling, New York City, christen the craft. Mrs. Balling is the wife of the president of the Esso Export Corp.

Destined for use in New York harbor the Esso Dispatch will shuttle supplies to tankers during their stay in port. This vessel is being built for the Butterworth System Inc., Bayonne, N. J. a subsidiary of the Esso Shipping Co.

The Esso Dispatch is 116 ft. in length with a beam of 30 ft. and a 10-ft. storage depth. The vessel is powered by a 575 hp. Fairbanks Morse diesel engine and can develop a 10½-knot speed.

Equitable Equipment Co., Inc. whose main office is at 410 Camp St., New Orleans 12, La., specializes in many standard items of floating equipment, including tugs, quarterboats, crewboats, etc.



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WITH DIVERSEY PRE-WELDING TREATMENT FOR ALUMINUM

The BEST Surface Preparation . . .
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Produces the BEST Spot Welds!

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- . . . produces low-uniform surface resistance
- . . . improves quality of welds
- . . . increases quantity of spot welds before tip cleaning
- . . . prolongs life of electrode tips
- . . . eliminates tedious, expensive mechanical cleaning

Yes, if you are looking for higher quality, increased production and lower costs with your aluminum alloy spot welding operation, investigate the Diversey Pre-Welding Treatment today!

Used by leading aircraft companies, case histories reveal that, by employing Diversey No. 36 to remove identification markings, grease, dirt; and by using Diversey No. 514 to remove oxide and heat scale, spot weld output increased up to 50%! Further, plants report an increase up to 1,000% in the number of spot welds now made before the electrode tips require redressing!

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Please send me complete information on the Diversey Pre-Welding Treatment for Aluminum.

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DM4

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Metal Industries Department

1820 Roscoe Street • Chicago 13, Illinois

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100 Adelaide Street West, Toronto, Ontario

Figure 1

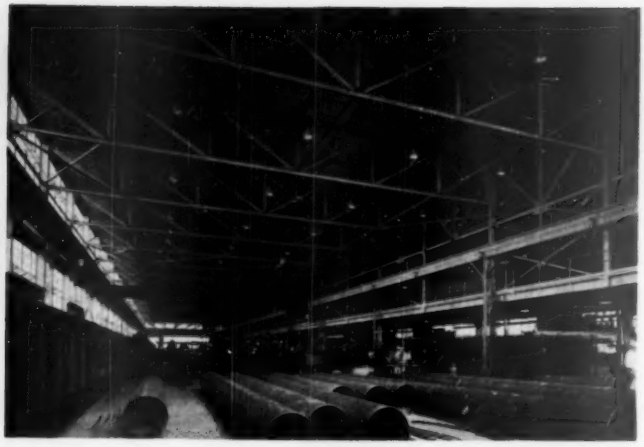

Figure 2

Producing Welded Pipe

The A. O. Smith Corp. of Texas is already shipping 30-in. welded steel pipe for the thousand-mile natural gas transmission line from southeast Texas to Chicago from this new $5 million plant, which was designed, built and equipped by The Austin Co. in a period of nine months. Forty-foot lengths of 30-in. diameter pipe, shown in figures at the end of the production line, are ready for loading into cars on the enclosed railroad siding, shown on the left, Fig. 2.

In the machine shown at left in Fig. 1, a 40-ft. cylinder is flash-welded simultaneously along its entire 40-ft. length. Edges of the steel cylinder are brought to white heat electrically, pressure is applied and the metal is fused. When the steel cylinder emerges from this process, it is ready for finishing touches and soon will be on its way to become part of a natural gas pipeline.

Use of standard 80-ft. welded H-section trusses with 40-ft. jack trusses, supplied from The Austin Company's fabricated stock, played an important part in speeding up the job. There is a 33-ft. clearance below the trusses in the plant's two 675-ft. long craneway aisles. Employee facilities, tool rooms and other service facilities are concentrated in an intermediate 40-ft. aisle, shown on the right, Fig. 2, where mezzanines have been provided.

New Western Insulated Wire Co. Plant

Western Insulated Wire Co., manufacturers of insulated electrical cords and cables, announce that they have completed removal of equipment and materials and are now in operation at 2425 E. 30th St., Los Angeles 58, address of the first 40,000 square foot unit of their new plant.

The half million dollar factory will be devoted to the manufacture of Neoprene- and rubber-jacketed portable cords and cables, asbestos insulated wires and cables, miscellaneous cords, fixture and communication wires and cables and Bronco 60 Certified Welding Cable.

WELDING CONNECTORS
Saxe System Welded Connection Units
for welded assembly

Saxe Units place in position and securely hold together structural parts to be welded.

As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.

"Write for 58 pg. Manual containing full engineering design information for welded structures."

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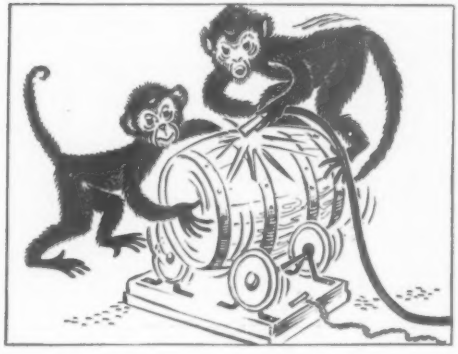
You're Smart Like a Fox...

when you increase arc-time per hour with Worthington-Ransome Welding Positioners and Turning Rolls.

Not this... Spare your welders the chore of having to *climb* all over the work piece. Climbing, turning, propping time is *waste* time.

But this With a Worthington-Ransome Welding Positioner continually bringing work into position for convenient down-hand welding, your welders spend less time handling, more time welding.



Not this... Why do it the hard way when you can get it done the easy way?

But this Manual or automatic welding really pays off when you use Worthington-Ransome Turning Rolls to rotate the work. This way, output goes up as much as 50% on either repetitive or job work.

Welding Positioner capacities from 100 lb to 20 tons. Turning Rolls from 3 to 150 tons, stationary and self-propelled.

Write for Positioner or Turning Roll Bulletin, Worthington Pump and Machinery Corporation, Welding and Assembly Positioning Equipment Division, Dunellen, N. J.

WORTHINGTON

NEW LITERATURE

New Milburn Catalog

Alexander Milburn, Inc., Baltimore, has issued a new catalog illustrating and describing the entire line of Milburn equipment. The line includes oxyacetylene cutting and welding apparatus, regulators for oxygen, acetylene and other gases, accessories and other supplies, portable carbide lights.

Superseding previous catalogs issued by both Milburn and The Black Mfg. Co., the new book contains a complete cross-reference index of part numbers so that holders of old catalogs can order new or replacement parts without difficulty.

Copies may be obtained by writing to: Alexander Milburn, Inc., 1231–45 Ridgely St., Baltimore 30, Md.

New Burdox Catalog

A new complete 64-page catalog of welding and cutting equipment and supplies and safety equipment has just been prepared by The Burdett Oxygen Co., Cleveland, Ohio. This new catalog illustrates and describes in detail the most modern and efficient equipment used in the welding field today. The new catalog describes not only the actual equipment required for every type of welding and cutting job, but also protective equipment such as goggles, helmets gloves, etc.

Copy of this new catalog is available upon request to Burdett Oxygen Co., Dept. I, 3300 Lakeside Ave., Cleveland 14, Ohio.

Who Knows—And What

Selected readers have received, or shortly will receive, from The A. N. Marquis Co. requests for information pertaining to their personal specialities within their occupational fields. Information submitted will be reviewed to determine suitability for inclusion in the company's new and unique reference work, *Who Knows—And What*, the Second Edition of which has been put into immediate compilation following the widespread acceptance of the First Edition, published earlier this year.

The unique reference value of *Who Knows* stems, according to the publishers, from two major features:

1. The inclusion of only those persons having special skills or knowledge in one or more of thousands of highly-specific topics judged by the editors to be subject to general reference interest, together with information on research and experience in these fields; general public or professional eminence is not a deciding factor in selections.

2. The Locator Index, which refers the user by means of a simple key to the listing of any person in the book having special knowledge about any one of the subjects included in the Index.

The company, which also publishes *Who's Who in America*, will welcome any suggestions from readers. Communicate directly with the company at 210 E. Ohio St., Chicago 11, Ill.

Arc Welding Lessons for School and Farm Shop

A text for Vo-Ag high schools, colleges teaching agricultural engineering and farmers. Contains 8 informational and 17 operational lessons, 343 pages, and over 550 photographs, drawings and tables. Bound in black, semiflexible, gold-embossed, simulated leather; price $1.00 in the U.S.A., $1.50 elsewhere, postage prepaid; published by The James F. Lincoln Arc Welding Foundation, Cleveland 1, Ohio.

"Arc Welding Lessons for School and Farm Shop" was written by Harold L. Kugler, Professor and Teacher Trainer Farm Mechanics, Agricultural Engineering Dept. Kansas State College of Agriculture and Applied Science.

It is a book to be used as a basic reference in developing skills involved in operating arc-welding equipment and has been prepared to supply the need for basic instruction material for teaching vocational agriculture students at the high school level. It is suitable, however, for use in agricultural engineering shop mechanics courses as well as for use in shops on farms.

The book contains 8 informational lessons providing general information on welding, 17 operational lessons intended to teach arc-welding skills, over 75 welded shop projects and an illustrated glossary. The lessons can all be studied separately so that assignments can be made to one particular subject or the book can be studied as a complete course in arc welding. Each lesson, in addition to the presentation of information in the text, has a class outline which gives the lesson objective and suggests teaching techniques for achieving the objective. Key points for discussion and illustration are outlined. A step-by-step analysis of a typical job gives students a "learn by doing" method of reaching each lesson objective.

The 8 informational lessons cover such subjects as progress in arc welding, controlling distortion, selecting welding electrodes, protecting health through safe practices, etc.

Part II covering the operational lessons cover such subjects as striking an arc and running a flat bead; butt welding in flat position; welding in overhead position; welding sheet metal; welding cast iron; building up worn parts; shaping, bending and forming metal with the carbon arc torch; hard-facing with arc welding equipment, etc.

Welding High Tensile Steels

A booklet on "The ABC's of Welding High Tensile Steels" has just been issued by Arcos Corp., welding electrode manufacturers of Philadelphia, Pa., to guide buyers and users of low-alloy, low-hydrogen electrodes.

It shows the importance and effectiveness of low-hydrogen electrodes in welding low alloy, high tensile steels, mild steel under highly restrained conditions and sulphur-bearing free-machining steels.

In the past, steel producers have often recommended mild-steel electrodes for these classes of welding. But with the development of the new Tensilend series of low-hydrogen electrodes by Arcos Corp., certain advantages have been secured which mild-steel electrodes do not offer. These are elimination of preheat and the elimination of underbead cracking.

In simple question and answer form, the booklet compares mild-steel and low-hydrogen electrodes, as related to preheating, underbead cracking, moisture in the arc and in the coating, burn-off rate, cost of operation, applications and stress relieving of the weldments

The Properties of Metallic Materials at Low Temperatures

The Properties of Metallic Materials at Low Temperatures, P. Litherland Teed. An introduction to the subject—including experiments on low-temperature changes in properties of aluminum, ferrous alloys, magnesium alloys, steels, copper, nickel, zinc, tin and lead.

Despite the immense advances made in experimental and theoretical physics, it is still impossible to predict what will happen to a metal at one temperature by using data collected at another temperature. Therefore, this book is in the form of a critical survey of a large number of experiments rather than a dissertation on formulas of thermodynamical origin. Each chapter deals with a restricted aspect of the subject.

The Properties of Metallic Materials at Low Temperatures begins with a review in broad outline of the subject in relation to fundamental physics. Seven chapters are devoted to a consideration of some of the major mechanical properties at low temperature of alloys of aluminum, iron, magnesium, copper, nickel, zinc, tin and lead. Ferritic and austenitic steels, because of their outstanding importance as engineering materials, receive three chapters. After describing the structural build-up of the metal, the process of mechanical deformation is described and the effects of deformation and of heat

treatment are considered. A brief account of the ways in which a structure can be examined and determined is also given.

Information is offered on the influence of low temperatures on such mechanical properties as: limit of proportionality; yield stress and ultimate stress in tension and compression; yield stress and ultimate stress in shear; yield stress in bearing; elongation and reduction of area; notched impact strength and notch sensitivity under static loading; limiting fatigue stress for notched and unnotched specimens; Young's modulus, shear modulus, bulk modulus; and Poisson's ratio.

Price $3.50. Published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y.

This is Volume I in a series of monographs published under the auspices The Royal Aeronautical Society.

Designing with Aluminum Extrusions

Basic engineering principles for most effective use of extruded aluminum shapes are well explained and illustrated in the 1950 edition of the 138-page book, *Designing with Aluminum Extrusions*, just issued by Reynolds Metals Co., 2500 S. Third St., Louisville 1, Ky. The books are available without charge to engineers, architects, designers and others requesting them on company letterhead.

The new book breaks down the advantages of the extrusion process into eight principles of design. Then each of these is illustrated and explained in detail by use of diagrams, charts and pictures of actual parts.

The section on examples of effective extrusion design contains more than 140 illustrations showing details of specific applications. This section alone contains a wealth of material to "trigger" the designer's imagination.

The section on manufacturing possibilities explains the broad range of shapes that can be produced by the extrusion process. Another chapter correlates shape design with manufacturing limits and shows how many of these limitations can be offset by proper design.

Since certain extruded shapes are used as structural or load-carrying members, a chapter is devoted to the principles of structural design.

The characteristics of aluminum itself, the selection of the correct alloy and temper, fabricating properties including welding, finishes and cost factors are also covered as separate chapters in the book.

This 138-page, 6 x 9-in. pocket-size book is complete with more than 390 illustrations, a table of contents, index of tabular material, index of illustrations and an itemized cross index covering text, illustrations and tables. It is wirebound to lie flat when open. The book was written by H. V. Menking, Assistant Director, Technical Service Dept., Reynolds Metals Co., Louisville, Ky.

Hardfacing

Welding Products, for Hardfacing and Repair, is the title of a new catalog re-

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IN WELDING

IN CUTTING

IN SAFETY EQUIPMENT

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Time lost in preparation, in looking for tools, in makeshift arrangements costs you money! You can't expect your men to do good work without good tools and accessories. Get the best in welding, cutting and safety equipment without paying premium prices by specifying BURDOX. Typical of the outstanding value and high quality of the entire BURDOX line are the products shown below. Made by welding men for welding men they reduce lost time, improve performance. Write for free catalog today and start saving with BURDOX at once!

CYLINDER TRUCKS DELUXE MODEL—The greatest cylinder truck value you've ever seen! Streamlined one-piece safety handle. Streamlined tool tray and rack. Bicycle type wheels with solid rubber tires. All welded construction. Chain holds cylinders securely.

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TRIP-L-ITE FLINT LIGHTERS—Lasts three times as long as ordinary lighters. Produces a hot, fat spark every time. Works easy. Insures instantaneous lighting.

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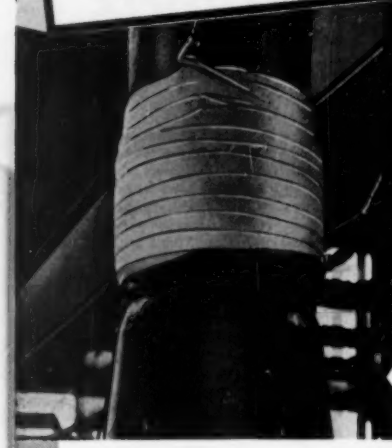
Arc-welding Distributor

HOW WOULD YOU HEAT A HIGH PRESSURE WELDED PIPE JOINT TO 1700° F. 30 FEET UP IN THE AIR?



Do It With

Smith-Dolan Preheating Stress Relieving and Normalizing Equipment-By-Induction-Heating at Low Frequencies.

Welded Joint in 20" O.D. — 1 3/8" Wall Carbon Moly Boiler Down-Comer Partially Wrapped for Stress Relieving.

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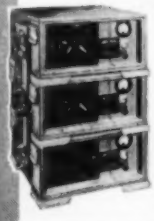
- **Proper heating is delivered according to set specifications and requirements of the Boiler and Piping codes.**



NEW MODEL U-P — *Patented Smith-Dolan System, portable, low frequency induction heater, three-high stack (shown) 30 kva, 10 kva per unit. Buy one or stack two or three for increased capacity. Buy what you need; build as you go.*

AUTOMATIC CONTROL CABINET *used with Model U-P units (shown) and Model GC Duplex 120 or 150 kva induction heaters (shown in catalog).*

Electric Arc equipment can be rented or purchased for any job requiring preheating and stress relieving for welding and normalizing.

Write for Informative Catalog

ELECTRIC-ARC INC.

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161 JELLIFF AVE., NEWARK 8, N. J.

AC & DC Welding Equipment • Spot Welder Electrodes & Supplies

leased by the American Manganese Steel Div. of American Brake Shoe Co.

This bulletin carries a description of the rods, electrodes and other welding products manufactured by AMSCO, giving composition, properties and typical applications.

In addition, recommendations are made as to the proper rod for use on basic parts in 15 different industries.

Graphic comparisons are shown of the abrasive resistance, hardness, impact resistance, etc., of the AMSCO line, together with an explanation of the factors involved in proper selection of hardfacing rods for specific applications.

Ask for bulletin 650-W. Send your request to American Manganese Steel Div., 389 E. 14th St., Chicago Heights, Ill.

Fluid Pressure Boosters

Miller Motor Co.'s new, 12-page, well-illustrated bulletin B-200 tells how this company's line of low cost production-line fluid pressure boosters can be employed to save space and weight, cut costs and increase efficiency in clamping, punching, shearing, stamping, crimping, welding, pressing and similar applications accomplished by compressed air or hydraulic power.

Bulletin B-200 available at no charge from the manufacturer, Miller Motor Co., 4027 N. Kedzie Ave., Chicago 18, Ill.

Steel Castings Handbook

1950 Edition, Completely Revised, Contains 522 Pages, 440 Illustrations and 120 Tables

Recognized as the outstanding reference volume on steel castings and the steel castings and the steel casting industry since its initial publication in 1941, the *Steel Castings Handbook* has been entirely revised, expanded and brought-up-to-the-minute in the 1950 edition just published under auspices of Steel Founders' Society of America.

Rewritten, enlarged and reorganized throughout, the new edition represents a complete revision of the original volume, which was last reprinted for the third time in 1945. It is considered outstanding in the completeness of its information on types of steel castings, specifications, design considerations, applications, mechanical and physical properties of cast steel, and other comprehensive technical data covering virtually every facet of the industry, its products, processes, history and outlook.

Engineering properties are discussed at length in another chapter which deals separately with cast steel under repeated stress, hardness, wear resistance, machinability, corrosion resistance, heat resistance and weldability.

Of particular usefulness is a five-page section listing recommendations to purchasers of steel castings, and separate chapters devoted to steel-casting specifications and common definitions of frequently used foundry terms.

Chemical compositions of standard steels are dealt with informatively in the appendix. All material in the volume is closely indexed.

This Lukens man *knows*...

Use "140" MONEL electrodes for welding the clad side of Lukens Monel-Clad Steel

"When customers ask us to recommend a welding rod for the clad side of our Monel-Clad Steel, we tell them to use the new '140' Monel electrode."

These are the words of Mr. L. W. Williams, Manager, Technical Service, Lukens Steel Company, Coatesville, Pa. Mr. Williams' expert advice on metal problems is sought by many users of his company's products.

In explaining his reasons for recommending "140" Monel® electrodes, Mr. Williams said:

"The '140' Monel electrode was especially designed to lay its deposit directly on steel. Since the ductility of the deposit, arcing characteristics and slag removal are unaffected by steel pick-up, there is no need for the customary barrier layer of Nickel.

"Moreover, we know that the customer can be sure the welds he makes with the '140' Monel electrode will meet various code requirements and pass X-ray inspection."

EMBLEM OF SERVICE

INCO

TRADE MARK

In addition to welding the clad side of Lukens Monel-Clad Steel, "140" Monel electrodes give good results in any Monel welding application where steel is present... making Monel overlays on steel, joining Monel to steel or stainless steel.

"140" Monel electrodes are produced in standard diameters of 3/32", 5/32", and 3/16". Current requirements are – D.C., reversed polarity.

For additional information about the welding of Inco Nickel Alloys, write for: *Bulletin T-2, "The Welding, Brazing, and Soldering of Monel, Nickel, and Inconel."*

NOW—FOR YOUR CONVENIENCE—Inco welding electrodes are now supplied in new containers... easier to open, better protection during shipping and storage.

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y.

Acclaimed by industry

TORCHWELD® "6500"

"We now get two-stage regulator performance . . . at single-stage regulator cost . . ."

"Delivers pressures that do not vary as the cylinder empties . . ."

"Most accurate regulator I have ever used regardless of price . . ."

"Gives steady gas-flow for hour-after-hour welding . . ."

"Plenty of volume for heavy-duty cutting right down to the end of the cylinder . . ."

"One setting is enough to do any job . . . and readjustments are never necessary . . ."

"Not just good performance . . . but rugged construction and easy maintenance, too . . ."

Here's why Torchweld "6500" delivers constant pressure and volume regardless of cylinder pressure

In any regulator the pressure of the incoming gas is one of the forces operating the valve mechanism. As cylinder pressure drops, this force decreases, causing a variation in the volume of gas flowing through the valve.

In the TORCHWELD "6500", a pressure compensating chamber below the seat counteracts the effect of this decreasing force.

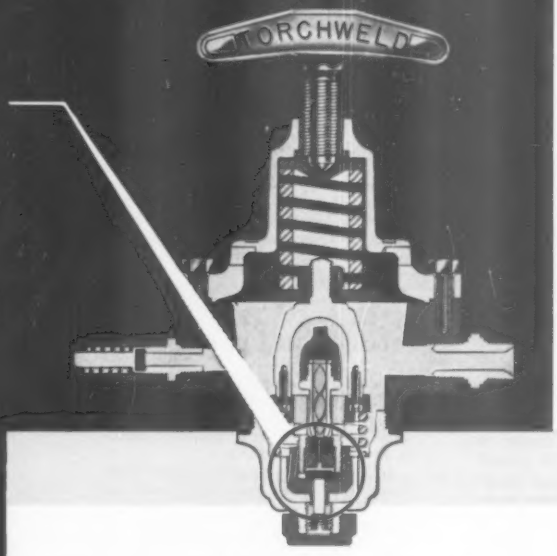
A small passage in the valve seat permits gas at *cylinder pressure* to enter the chamber. At the bottom of the chamber is a reinforced rubber sealing disk. Below the disk is a pin which rests against the back of the regulator.

The forces within the chamber act upon the disk and pin so that there is a resultant effective force which tends to move the seat upward toward the nozzle.

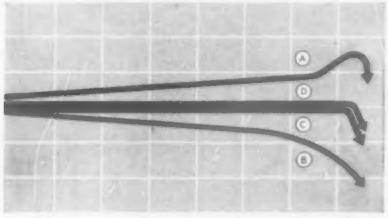
As cylinder pressure drops this upward force diminishes, resulting in a gradual increase of the spacing between seat and nozzle. This compensates for the effects of decreasing cylinder pressures, and thus maintains constant delivery pressure and volume.

as truly revolutionary!

REGULATOR with pressure compensating chamber



Here's how various types of regulators act as cylinder pressure drops



Ⓐ *Stem-type* single-stage regulator delivers at *increasingly higher* pressures as the cylinder empties. Frequent pressure adjustments are necessary.

Ⓑ *Nozzle-type* single-stage regulator delivers gas at pressures that *drop lower and lower* as the cylinder empties. Frequent pressure adjustments are necessary.

Ⓒ *Two-Stage* regulator gives uniform working pressure regardless of cylinder pressure, depending upon quality of regulator. Pressure adjustments are avoided.

Ⓓ TORCHWELD "6500" REGULATOR delivers constant working pressure (whatever it's set for) regardless of drop in cylinder pressure. No adjustments are necessary to maintain desired flame characteristics.

Plants and welding shops everywhere are buying the TORCHWELD "6500" to get the best performance at the least cost

It costs only slightly more than the average single-stage regulator, but it gives the precise control heretofore available only in higher-priced two-stage regulators. That's the reason the TORCHWELD "6500" is the wise choice wherever regulators must be replaced, or new equipment ordered.

Acclaimed the first major advance in regulator design in 20 years, the TORCHWELD "6500" is a brand new *type* of regulator, combining the advantages of both single and two-stage regulation without the disadvantages of either.

The TORCHWELD "6500" delivers precise and constant working pressure (at whatever setting you choose) *regardless of decreasing cylinder pressure.* This is made possible, at a price to please every pocketbook, by the unique NCG-engineered *"pressure compensating chamber"*—an exclusive feature.

What's more—the "6500" has all the quality refinements characteristic of TORCHWELD—extra-big streamlined gas passages, exclusive "SPIREX" nozzle element that prevents seat ignition, inlet filter, relief valve, rugged construction and few working parts to wear or repair. Better write *today* for Bulletin No. NTW-104 and get *all* the details.

NATIONAL CYLINDER GAS COMPANY

Executive Offices: 858 N. Michigan Avenue, Chicago 11, Illinois

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Please send me a copy of Bulletin NTW-104 containing full particulars on the sensational new TORCHWELD "6500" regulator.

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TWO-STAGE
REGOLATOR

Precision Regulation
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OXYGEN
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The precision performance of the two-stage RegOlator is especially desirable for piped distribution systems and other applications where large volumes of high pressure gases must be controlled accurately.

Two-Stage RegOlator Gives You Plus Performance!

Constant delivery pressure regardless of drop in pressure at the inlet...Patented design incorporates nozzle-type first stage counterbalanced by stem-type second stage... Triple action cartridge filter eliminates troubles usually caused by rust, dust or dirt.

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4201 West Peterson Ave. Chicago 30, Illinois

PIONEER AND LEADER IN THE DESIGN AND MANUFACTURE OF PRECISION EQUIPMENT FOR USING AND CONTROLLING HIGH PRESSURE GASES

A limited number of copies of the 1950 *Steel Castings Handbook* has been printed. The price is $4.00. Copies may be obtained by writing to F. Kermit Donaldson, Executive Vice-President, Steel Founders' Society of America, 920 Midland Bldg., Cleveland 15, Ohio

Helpful Table Available in Edward Valves' Magazine

Included in the most recent issue of Valve Values, house organ of Edward Valves, Inc., East Chicago, Ind., is a helpful pressure-temperature rating table conforming to A.S.A. B16e6-1949.

This table on the inside back cover of the publication is compactly arranged for filing and for use under the glass tops of desks and is valuable for engineers concerned with pressure-temperature piping work. The ratings are used as standard by the A.S.M.E. Boiler Code Committee, the A.S.M.E. Code for Pressure Piping, most A.P.I. divisions and others.

In the same issue of Valve Values, an article describes in detail new testing techniques used in the design of Edward valves for lower pressure drop and minimized turbulence. The new Edward laboratories are also described and pictured.

Metals at High Temperatures

This book, *Metals at High Temperatures*, by Frances H. Clark, Consulting Metallurgist, is a compilation of the most recent available data on the properties of metals at elevated temperatures.

It is designed primarily to cover heat-resistant alloys and special alloy steels but includes other metals such as aluminum, lead and magnesium alloys. The text is introduced by a theoretical discussion on the plasticity of metals with special reference to high temperature effects.

There is a vast amount of essential tabular data giving the properties of all the latest alloys which have been developed for service at extremely high temperatures.

A full discussion is devoted to the phenomenon of creep in metals and alloys and every effort has been made to include all the most relevant data on this important property. There is also a section on test methods for metals at high temperature and current manufacturing methods for heat-resistant alloys.

All the information presented has been subjected to critical evaluation and interpretation.

This book is intended for all who are concerned with the engineering and metallurgical aspects of high temperature service, particularly in reference to turbojet airplane engines where these alloys are playing a critical part. Numerous other high temperature demands are being made upon alloys in military uses, such as rockets, projectors, gun barrels, etc. All metallurgists and mechanical engineers will welcome its abundance of easy reference information. 363 pages. Price $7.00. Reinhold Publishing Corp., 330 W. 42nd St., New York, N. Y.

Increase the life of *Wearing* parts

This NEW booklet tells you how

Every manufacturer or user of metal parts . . . every welding engineer, master mechanic, maintenance superintendent, and plant foreman . . . should have a copy of this really *complete* booklet on hard-facing. It takes all the guesswork out of choosing the right alloy, the right welding process, and the best welding procedures for applying the rod.

Use the coupon below to order your copy of this 40-page booklet. You'll find it a big help in solving most of your hard-facing problems.

Here is What's in it—

Which Metals Can Be Hard-Faced—

A 2-page chart listing 21 metals . . . and recommending suitable hard-facing rods for each.

How to Select the Right Rod—

Factors to consider in making your selection and a comparison of the characteristics of hard-facing deposits.

Which Welding Process to Use—

Where and why to use oxy-acetylene, metallic-arc, HELIARC, mechanized oxy-acetylene, or UNIONMELT welding for applying hard-facing materials.

How to Make the Deposit—

Detailed, step-by-step instructions for applying HAYNES hard-facing alloys by both the oxy-acetylene and metallic-arc welding processes.

Properties of HAYNES Hard-Facing Alloys—

Description, properties, and available sizes of 12 hard-facing materials.

"Haynes," "Heliarc" and "Unionmelt" are trade-marks of Union Carbide and Carbon Corporation or its Units.

HAYNES Trade-Mark Alloys

Haynes Stellite Division
Union Carbide and Carbon Corporation
UCC

USE THIS HANDY COUPON

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Please send me, without obligation, a copy of the new booklet, "HAYNES Alloys—Hard-Facing Manual."

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NEW PRODUCTS

High Production Electrode

The Champion Rivet Co., Harvard Ave. & E. 108th St., Cleveland 5, Ohio, announce their newly developed Gray Devil H. P. Electrode. This is an E-6012 Electrode especially designed for high-production applications at high-welding currents. A folder fully describing the properties of this electrode is available on request.

Pipe Scarfing Attachment

A new and versatile pipe-scarfing attachment has been developed for use with the Kinmont Universal Power Unit, manufactured by Roylyn, Inc., of Glendale, Calif.

This accessory provides an economical means of accurately cutting or scarfing pipe or tanks while they are being turned by the Power Unit. The attachment is easily installed through existing bolt holes, without modification or the use of special tools.

Provision is made for vertical and horizontal adjustment of the cutting torch. A protractor dial provides for angular adjustment. The scarfing attachment is conveniently hinged to swing the torch out of the way while changing the work, without disturbing the adjustments.

Extension rods are steel. The $^{3}/_{8}$-in. I.D. Torch Tip Holder is supplied with brass-tip adapter bushings in sizes of $^{1}/_{2}$, $^{9}/_{16}$, and $^{41}/_{64}$ in. to accommodate the majority of cutting torches in use.

For further details, write or call, D. L. Leavitt, Vice President, Roylyn, Inc., 718 W. Wilson Avenue, Glendale 3, Calif. Telephone CHapman 5-2581.

Stud Welding Control Unit

A new control unit, believed to be the only one in this country specifically designed for the shielded (inert gas) stud welding of aluminum, stainless steel, etc., is currently being marketed by the Shielded Stud Welding Co. of Los Angeles.

It provides electronic timing control for the weld period, and also automatic (pneumatic) timing control of the inert gas prior to and after the weld.

The attractive control unit is portable, ruggedly built to withstand heavy industrial use, and is manufactured to precision standards. Calibrated adjustment dials are mounted on a dead front panel which protects the operator from shock when making adjustments. Rigidly mounted fittings are conveniently located on one side of the enclosure providing connections for arc welder and stud gun, inlet and outlet gas hose, control cable, and 110-v. power supply.

The unit also incorporates a solenoid valve for the control of the inert gas and a high-speed magnetic type contactor which is specially designed for frequent short timing periods and heavy loads.

Some of the advantages claimed by using this unit for stud welding are: (1) higher quality stud welds, (2) enhanced corrosion resistance of stainless steel stud weld, (3) elimination of need for ceramic ferrules in many instances and (4) savings in inert-gas consumption.

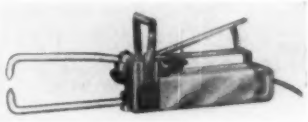
Full information may be obtained by writing to: Shielded Stud Welding Co., 124 W. 4th St., Los Angeles 13, Calif.

Portable Spot Welder

Increased power, faster welding, easier handling, automatic switch control and greater versatility are standout features of a new self-contained portable spot welder—model BW—now being manufactured by Greyhound A. C. Arc Welder Corp., 606 Johnson Ave., Brooklyn 6, N. Y., it was announced recently.

To answer the need of metal-working shops which require a floor type as well as a portable spot welder, the versatile new welding tool can easily be converted into a stationary model.

Although the new portable welding tool weighs only about 33 lb., it can weld up to $^{1}/_{4}$ in. combined thickness of mild or stainless steel, or 2 pieces of 16 gage galvanized metal with a combined thickness of $^{1}/_{8}$ in. This capacity is said to be almost double that of present models.



Automatic switch control eliminates any finger movement. This results, reports the manufacturer, in faster production, less fatigue to the operator, easier handling and better and more uniform welds.

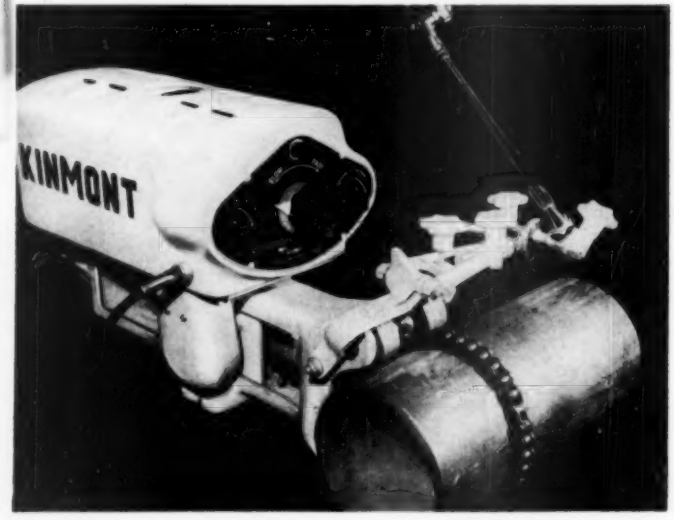
There is no waste motion. A slight squeeze of the spot welder handle applies pressure to the welding tips. An extra squeeze of the handle automatically turns on the current. Release of pressure automatically cuts off the current and separates the welding tips.

The protruding copper welding arms are available in 3 interchangeable lengths—6, 12 and 18 in.—as well as in a variety of special shapes and sizes. For heavy gage intermittant production, Greyhound can furnish special water-cooled arms and tips to insure maximum efficiency and to prolong the life of the tips.

For consistently flawless and uniform welds, the new BW portable spot welder can be operated with a BW Timer which can be adjusted to automatically cut off the current after any desired timed well.

When mounted on a specially designed Greyhound metal stand, the portable welder becomes an easy to use and highly efficient stationary model, according to the manufacturer. Operating pressure is applied through a foot pedal, thus freeing the operator's hands. The unit can again be used as a portable welding tool simply by removing 2 metal brackets holding the spot welder to the stand.

Company spokesmen describe the new unit as an effective self-contained and self-operating portable spot welder for sheet metal, auto and truck body shops. It is said to be an essential tool for all plant maintenance shops, and is also highly recommended for use by manufacturers of



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Westinghouse

NEW D-C WELDER CUTS COSTS...ENDS NOISE ...FREE TRIAL PROVES IT!

★ **SAVES $126 A YEAR IN POWER COSTS ALONE!** New Westinghouse D-C Welder has no-load loss of only 500 watts, compared to 2480-3600 on a conventional motor-generator welder.

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★ **SIMPLICITY SLASHES OPERATING COSTS!** Only 3 basic elements—transformer, reactor and rectifier. New D-C Welder occupies less space, has no brushes, armatures or bearings to replace or repair —no moving parts to clean or lubricate.

★ **SMOOTHER WELDING...** Less arc blow... easier arc striking... better weld quality.

FREE TRIAL!

We'll arrange DEMONSTRATION OR TRIAL INSTALLATION... at no cost to you. Contact nearest distributor, or write Westinghouse Electric Corporation, Dept. DC19, P. O. Box 868, Pittsburgh 30, Pa.
J-21593

Westinghouse
D-C Welders

blowers, air-conditioning and ventilating systems, skylights, neon and fluorescent display fixtures, wire frames and fences, kitchen equipment and other fabricators of metal products.

New Liquid Prevents Fogging on Glass and Plastic

A new liquid which prevents fogging of glass and transparent plastic in humid atmospheres and at low temperatures has been announced by Master, 4444 Brooklyn Ave., Los Angeles 22, Calif.

Fog-gone, the new product, has been extensively tested under widely varying conditions and, according to the manufacturer, remains effective for a longer period of time and at lower temperatures than any other similar product. A single application has prevented fogging for more than three weeks.

Fog-gone has been proved effective for a broad range of applications, including eyeglasses, safety goggles, welder's hoods and shields, refrigerated cases, show windows, automobile, truck and airplane windshields and mirrors.

Packaged in a 4-oz. polyethlene plastic "squeeze-spray" bottle, Fog-gone is extremely easy to use. It is necessary to apply only a drop to each eye glass lens or a quick spray to larger glass surfaces and then wipe with clean dry cloth or tissue.

Coated Rod for Hardfacing

After extensive research and exhaustive tests, the manufacturers of Ranite have developed a new metallic-coated electrode for arc welding. The core wire is of high alloy cast material and the special coating further increases the alloy content of the weld.

The operating characteristics are unusually smooth. A soft arc results on a.-c. or d.-c., either straight or reversed polarity. Ranite No. 4 Electric, as the rod is called, leaves a slag-free deposit. For a rod of this type, there is a minimum tendency to check.

One of the features of this 18-in. Ranite electrode is that it can be gripped anywhere along the rod length. It is not necessary to grip the rod in the center or at the end. At 800° F. the Rockwell C hardness is 45. The ultimate hardness ranges from 56 to 60 on the Rockwell C scale. The weld can be hot forged.

The metallic coating means high recovery and deposition rate.

Among the uses for this rod are mill hammers, screw conveyors, mixing blades, cement grinding rings, pug mill knives and coke pusher shoes. Descriptive bulletin is available from Rankin Mfg. Co., 3072 W. Pico Blvd., Los Angeles 6, Calif.

Small Spotwelder

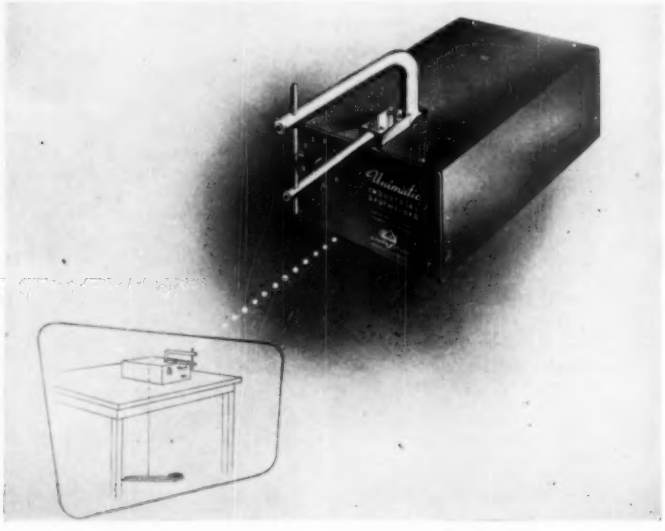
The new Unimatic Industrial Spotwelder is expecially designed for precise production welding of light gage wire and sheet metal. It is a stored-energy type resistance welder with an extremely short time-constant. This feature enables even inexperienced operators to make burn-free welds of greater strength—with no evidence of heat distortion, discoloration or splattering.

A ten-position selector switch allows a wide range of adjustment, where each setting provides a precise amount of energy to the weld. The unit is of simplified design having no tubes or complicated electronic controls, which means lower initial outlay and economical operating and maintenance cost. The Unimatic Industrial Welder is compact and portable...easy to move or bench mount into any production operation.

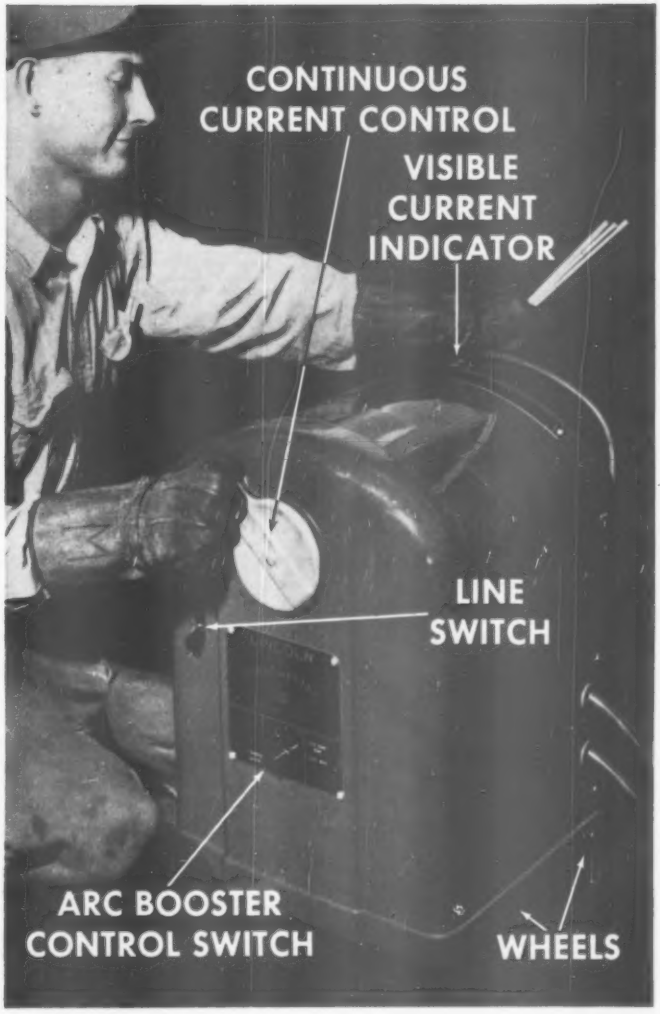
It is manually actuated by either push-button or foot-pedal control and is ready to operate when plugged into any standard 115 v. 60 cycle lighting circuit. Throat depth measures 6 in. and electrodes are adjustable pressure type. The Unimatic Spotwelder has big welder versatility and high-production capabilities. Experience has shown where one welder is purchased for a specific purpose, more and more jobs are built around it... in every application Unimatic Industrial Welders demonstrate their cost-cutting efficiency. The unit is designed to meet the exacting specifications necessary in the welding of precision instruments and their components. It is also particularly well adapted for use in light industry and laboratory. Manufacturers of radio, electronic and television parts; jewelry, aircraft, surgical, dental, telephone, optical and electrical equipment will all find many applications for the new Unimatic Industrial Spotwelder manufactured by Unitek Corp., located at 697 N. Lake Ave., Pasadena, Calif.

Stud Welding Power Sources

Development of two special power units, specifically designed for use with Nelson stud welding equipment, was announced recently by George E. Gregory, president of Morton Gregory Corp. One unit is a motor-operated generator set capable of welding studs up to and including 3/4 in. in diameter. The other is a specially designed battery-operated unit which can be used for installing studs up to



MORE AMPS..MORE RANGE
does more jobs at less cost



LINCOLN
"FLEETWELDER" 200 AC

HANDLES 5/64 to 1/4" RODS.
For sheet metal or heavy duty jobs.

NEMA RATED 30 TO 250 AMPS.
With a high reserve of extra amps.

WORLD'S EASIEST WELDING.
Arc strikes automatically with Lincoln pioneered "Arc-Booster".

MAKES STRONGER WELDS.
"Arc-Booster" gives instant penetration at start of weld.

LOW IN PRICE.
Sells for less than other welders of comparable capacity . . . *today's best buy in Industrial AC Welders.*

For Production, Maintenance, Job Shops

The most versatile AC welder on the market today. Precision-built to give you the highest quality welds . . . faster, easier and at lower cost. "Fleetwelder's" broad capacity covers a welding range normally requiring two welders of different sizes. Remarkable stable arc at low currents simplifies and speeds the welding of thin metals with 5/64" electrodes. Also permits heavy sustained welding at high currents with 1/4" diameter electrodes.

GET THE FACTS

Send for free "Fleetwelder 200" Bulletin 1301, write

THE LINCOLN ELECTRIC COMPANY
Dept. 910, Cleveland 1, Ohio

Sales Offices and Field Service Shops In All Principal Cities

LINCOLN

1/2 in. in diameter with the Nelson automatic stud welding gun.

"These two machines have been developed to improve and extend the cost-saving advantages of stud welding," said Gregory. "Both units have been designed to provide an adequate, dependable power source for stud welding under all operating conditions. The new power unit is superior to 600-amp. generators now available and is particularly effective for welding studs from 1/2 to 3/4 in. in diameter. The battery unit represents an excellent source of reliable power for stud welding wherever the voltages required for the operation of generators is not available."

In stud welding performance, the Nelson power unit is equivalent to two conventional 400-amp. generators in parallel, although its cost is approximately one-third less than the two units. The compact unit is comparable in size to a 200-amp. welding generator and weighs approximately 700 lb. Either 220- or 440-v., 60-cycle alternating current can be used with the new power unit.

The Nelson stud welding battery unit, requiring only a 110-v. a. c. convenience outlet for its operation, is particularly useful for construction jobs where welding generators or necessary power are not available, and for plant maintenance operations.

This unit consists of twelve 150 amp. top-quality wet storage batteries securely mounted on a strong frame and covered with an easily raised hood. Wheels are optional equipment. An automatic battery charging device is mounted on top of the hood. The unit weighs approximately 1100 lb. and, when used on construction work, may be conveniently moved on a trailer or pickup truck.

Both of the new units will be exhibited at the National Metal Exposition in Chicago, October 23–27. They will be sold through Nelson Authorized Dealers located in principal cities and the Nelson Stud Welding Division, Lorain, Ohio.

Tempilaq°

Tempil° Corp. of 132 W. 22nd St., New York 11, announces the development of additional high temperature ratings of Tempilaq° to indicate 1650°, 1700°, 1750°, 1800°, 1850°, 1900° and 1950° F.

Beginning with 113° F., Tempilaq° is now available in 12½-degree steps to 400° F. and in 50° steps from 400° to 1950° F.

Tempilstiks°, the crayon form of temperature indicator, and Tempil° Pellets are available in similar intervals from 113° to 2000° F. In addition, Tempil° Pellets can be supplied in 50° steps in the range from 2000° to 2500° F.

Packaged Electrodes

The Champion Rivet Co., Harvard Ave. & E. 108th St. Cleveland 5, Ohio, announce Champion Stainless-Steel Electrodes now packaged in metal containers with a self-sealing cover. Electrodes 5/32 in. diameter and smaller, will be packed in 5-lb. cans, six of which are packed in a fiberboard box for easy storage. Electrodes 1/8 in. diameter and larger will be packed in 10-lb. metal cans, six in a fiberboard container, net 60 lb., for convenient shipping and stroage. These metal containers are watertight and moisture-proof, keeping electrodes in first class condition. Covers can be readily replaced to keep partial contents fresh.

Welding Table

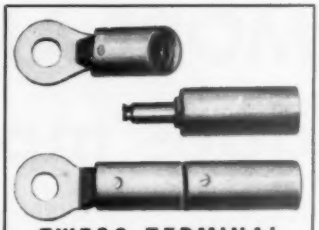
The Challenge Machinery Co., Grand Haven, Mich., has announced the addition of a semisteel Welding Table to its line.

Built of fine-grain special analysis semisteel, the table is six-inches thick and provides a rigid, smooth and perfectly square surface with tee-slots to facilitate assembling, locating and welding.

It is sold with an arc-welded, all-steel stand which makes a substantial base that has the strength and solidity of a one-piece unit. The stand is equipped with lock leveling screws, enabling the user to level his plate quickly and lock it securely. The number of screws varies from 19 on the 30 x 60-in. size to 59 on the 54 x 144-in. size.

This Challenge Welding Table is made in three standard sizes, 30 x 60, 48 x 96 and 54 x 144 in.; other sizes to order.

On special order, plates will be grooved and keyed so that two or more plates can be assembled and mounted into one complete unit. For example, four 54 x 144-in. plates can be put together to form one unit 144 x 216-in.



TWECO TERMINAL CONNECTORS

for Welding Machines

Bolt directly to positive and negative welder studs. Provide easy cable switch to reverse polarity. Simple cable disconnect for quick "Jump-In" of additional cable.

3 Sizes for cables #6 through 4/0

The male plug of TWECO "Sol-Con" and "Mec-Con" Cable Connectors fit the female part of TWECO Terminal Connectors. Sol-Con and Mec-Con Cable Connectors are COMPANION ITEMS.

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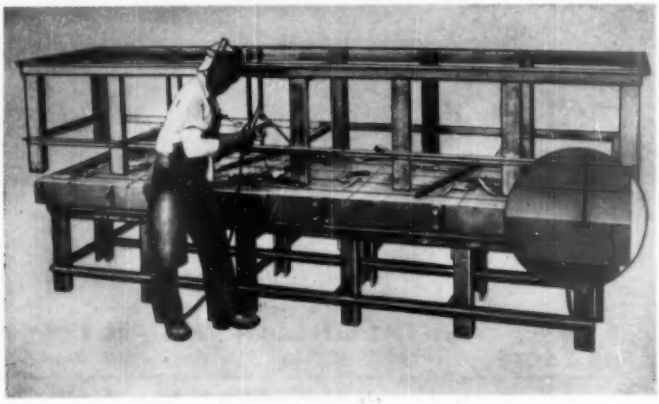

1 Hammer Set . . .

with the service life of 7!

This new Selector and Comparison Chart . . .

Describes the rods in the complete AMSCO Line

Lists the type of service recommended for each rod

Compares other makes for handy cross-reference.

Here are facts that help increase efficiency and economy in your hardfacing work. Write today for your free copy of Bulletin CC-3.

Hardfacing with AMSCO® TUNGSTEN CARBIDE made these Pulverizer Hammers last 600% longer!

Here's another case where the use of AMSCO Hardfacing Rod has resulted in saving hundreds of dollars—plus shorter and less frequent down time for repairs. The hammers above, used for pulverizing asphalt roofing trimmings, were subject to severe abrasion . . . average service was only 4 days. To stop such rapid and costly wear, the hammer tips were hardfaced with AMSCO Tungsten Carbide. Result? Instead of only 4 days, *the same hammers now last 4 weeks!*

Equally big savings are being made every day with AMSCO Tungsten Carbide—on such parts as:

Drill Bits	Cane Knives	Pug Mill Knives
Plowshares	Muller Plows	Hammermill Hammers

Wherever parts are subject to abrasion or impact . . . or wherever serrated cutting edges are used. . . . you'll find money-saving, time-saving applications for AMSCO Hardfacing Rods and Electrodes.

put LIFE into service with

AMSCO®
WELDING PRODUCTS

AMERICAN Brake Shoe COMPANY

AMERICAN MANGANESE STEEL DIVISION
399 EAST 14th STREET • CHICAGO HEIGHTS, ILL.

abstracts of
CURRENT WELDING PATENTS

Prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,516,100—Method of Welding Laminated Plates—Harry C. Boardman, Chicago, Ill., assignor to Chicago Bridge & Iron Co., a corporation of Illinois.

This patent covers a welded tank which has a laminated plate of at least four plies that carry opposed tension members secured to opposite sides thereof. A fused arcuate area is provided at the point of attachment of each tension member and these arcuate areas intersect each other at their innermost portions to bind the plies together.

2,516,777—Control Apparatus for Automatic Welding Heads—Floyd C. Knight and Elliott C. Cornell, Jr., East Cleveland, Ohio, assignors to The Auto Arc-Weld Mfg. Co., Cleveland, Ohio, a corporation of Ohio.

The patented control apparatus relates to an automatic welding head and it includes a d.c. motor that has a separately excited field with the armature of the motor being connected in parallel to the weld arc. A relay is also provided that has an operating coil connected in series with the motor and has a second operating coil connected in parallel to the arc so that the parallel operating coil will hold in the relay until a weld arc is struck. A high and a low resistance are connected to the relay which changes the armature circuit to insert higher resistance therein when starting the motor and place the low resistance into the armature circuit thereafter. The relay changes its position to remove the higher resistance from the armature circuit substantially simultaneously with the establishment of a weld arc.

2,517,574—Apparatus for Electric Welding Side Seam Portions of Can Bodies—Lyman L. Jones and George K. Barger, Seattle, Wash., assignors to American Can Co., New York, N. Y., a corporation of New Jersey.

A specialized apparatus of the character indicated is disclosed by this patent.

2,517,642—Oxygen Jet Metal-Cutting Nozzle—Cedric Dod, Giffnock, Scotland.

This patent discloses an oxygen jet metal-cutting nozzle that has therewithin a heating gas chamber and a cutting gas chamber each in communication with a respective gas supply source. The particular positioning and relationship of the gas passage and discharge passages are described in detail in the patent.

2,517,653—Portable Spot Welder—Ralph M. Gaston, Chicago, Ill., assignor, by mesne assignments, to Karma Mfg. Co., Harvey, Ill., a corporation of Illinois.

The portable spot welder patented is manually operable and positions a pair of electrode holders for carrying welding electrodes. Levers carry these electrode holders and are independently movable while detent means interconnect the levers so that when one is rocked about its pivot in one direction, the other is rocked about its pivot in the same direction but through a different angular extent.

2,517,739—Electric Arc Welding System—Joseph M. Tyrner, New York, N Y. and Nelson E. Anderson, Scotch Plains, N. J., assignors to Air Reduction Co., Inc., a corporation of New York.

This patent is particularly directed to a water-cooled arc-welding torch which has a manually controlled valve associated with the torch by which the operator can vary the amount of water circulated in the electrode cooling system. Variation in the flow of cooling liquid through the system operates a relay to control a device that is responsible for the supply of an operating medium to the welding torch.

2,517,798—Welding Electrode Assembly—Glenn S. McIntyre, Lansing, Mich., assignor to Kelsey-Hayes Wheel Co., Detroit, Mich., a corporation of Delaware.

McIntyre's welding electrode assembly includes a holder which has a detachable tip engaged therewith and a member having a partition extending substantially across the holder is also engaged with the holder. The various devices combined to form a passage for cooling medium through the electrode assembly.

2,517,853—Apparatus for Welding Tanks—Earl E. Eickmeyer and Samuel O. Mains, Dayton, Ohio, assignors to The Dayton Pump & Mfg. Co., Dayton, Ohio, a corporation of Ohio.

This special apparatus provides means for supporting a tank body and for rotating same with tank heads engaged therewith. Stationarily mounted welding means are provided adjacent the juncture of the heads and tank bodies as they are rotated for welding same together.

2,518,289—Electrode Holder—James C. Cox, Detroit, Mich., assignor to S-M-S Corp., Detroit, Mich., a corporation of Michigan.

This patent is particularly directed toward an adjustable clamp and separable clamping brackets are provided therein for positioning electrodes.

2,518,447—Welding Electrode—William A. Cannell and Maurice D. Woodruff, Springfield, Ohio, assignors to The Bauer Bros. Co., Springfield, Ohio, a corporation of Ohio.

This patent relates to an automatic electric welding machine wherein a pair of relatively reciprocable members are provided between which work to be welded is continuously advanced. The machine includes a sliding electrode support upon each of the members and resilient means maintain the supports in engagement with the members against the yielding resistance of which the supports are movable relative to the members in a plane parallel therewith. An electrode is fixed upon each of the supports and flexible electrical conductors connect each electrode with a source of electrical power. The electrodes are brought into engagement with the continuously traveling work for unison advancement therewith during which time the welding operation is completed.

2,518,463—Method of Electrically Welding Studs—Harold J. Graham, Detroit, Mich., assignor to Graham Mfg. Corp., Detroit, Mich., a corporation of Michigan.

Graham's welding method uses a stud-shaped metallic workpiece having a shank and a tip with the tip having a substantially reduced diameter and having an electrical resistance on the order of four times or more of the resistance of the shank portion of substantially the tip length. The method comprises spacing the stud piece from the workpiece and moving the stud piece toward a surface of the workpiece that causes, before the shank reaches the surface, arc formation between the tip and surface to melt and dissipate the tip metal. Thereafter the stud piece is forced into contact with the surface to consolidate the melted metal of the workpiece and stud.

2,518,543 & 544—Multiflame Heating Head—Franklin C. Hasse, Chicago, Ill., assignor to The Linde Air Products Co., a corporation of Ohio. Clifford C. Anthes, Union, N. J., assignor to The Linde Air Products Co., a corporation of Ohio.

What are you welding today, Joe?

"DIESEL FRAMES... and faster than ever with G-E W-32 ELECTRODES"

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NOW... With W-32, a low-hydrogen type electrode, you'll find it easy to weld "problem" steels—high-carbon, high-sulphur, steels of high hardenability which are susceptible to weld cracking, manganese steels, and steels to be enameled after welding.

Your G-E Welding Distributor maintains a stock of G-E electrode types to fit any welding job. Try W-32—see how it can save *you* money. If you'd like more information on W-32, ask him for a copy of GEA-4877. Or for information, write: *Apparatus Department, General Electric Co., Schenectady 5, N. Y.*

Using a-c or reverse polarity d-c, this all-position rod (AWS E6016) gives you:

- **Wide range of applications**
- **High impact strength and ductility**
- **High speed**
- **Greater crack restraint in high-carbon and hardenable low-alloy steels.**
- **Reduction of porosity in welding sulphur-bearing steels.**
- **Superior mechanical properties over conventionally coated types.**

ARC WELDERS • ELECTRODES • ACCESSORIES • RENEWAL PARTS

GENERAL ELECTRIC

These heating heads cover a multi-flame head comprising two gas mixing chambers. A nozzle having gas discharge ports directly connects with one of the chambers whereas a baffle is positioned in-between the chambers. These baffles have specially shaped gas ports therein for discharging converging gas streams to the chamber that communicates directly with the discharge ports, or else a special nozzle port is provided that communicates directly from the remote gas chamber to the atmosphere whereas the other nozzle ports connect to a second of the gas chambers.

Employment Service Bulletin

Position Vacant

V-244. Estimator Salesman wanted for established welding concern. Familiar with blueprints and estimating. Piping, Fabrication and Repair Work. Permanent position. Good opportunity for advancement. Salary open.

V-245. Salesman for Resistance Welding electrodes and machines. Philadelphia, South Jersey, Eastern Pennsylvania. Established distributor. Must know Resistance Welding. Salary and commission. Excellent opportunity.

V-246. Wanted: active and ambitious men, having experience in Resistance Welding and who are well acquainted with the industries in their area. To be appointed Sales and Engineering Representatives for a complete line of resistance welding machines of European manufacture with exclusivity of their territory. Liberal commission. Send description of experience and qualifications and outline the area you feel you can cover adequately

SECTION ACTIVITIES

prepared by C. M. O'Leary

Saginaw Valley

The following are the officers and chairmen committees for 1950–51 season. *Chairman*—Irving C. Mattson, Midland, Mich.; *Vice-Chairman*—Joseph E. Neuman, Saginaw, Mich.; *Secretary*—Morris D. Thomas, Flint, Mich.; *Treasurer*—John R. Clayton, Saginaw, Mich.; *Chairman Membership Committee*—Morris D. Thomas; *Chairman Program Committee*—Joseph E. Neuman and *Technical Representative*—Raymond J. Ladd, Midland, Mich.

Syracuse

The following are the officers and chairmen committees for 1950–51. *Chairman*—Millard Ames, Carrier Corp., Syracuse, N. Y.; *Vice-Chairman*—Harry E. Wolfe, N. Syracuse, N. Y.; *Secretary*—S. H. Monson, Syracuse, N. Y.; *Treasurer*—James Solar, Syracuse, N. Y.; *Chairman Membership Committee*—Harry Wolfe; *Chairman Program Committee*—Harry Miller, Syracuse, N. Y., and *Technical Representative*—James Hunter, Revere Copper & Brass Co., Rome, N. Y.

Western Michigan

The July meeting of the Executive Committee of the Western Michigan Section was held at Battle Creek, Mich., on July 7, 1950. The Grand Rapids group met at the Dobe Ranch in Hastings for lunch, then proceeded to the Clark Equipment Co. in Battle Creek where Paul Wagner escorted them through the truck plant. The group then went on to the Marywood Country Club for golf. In the evening, dinner and meeting was held at the American Legion Club. The committee thanked Bob Kline and Paul Wagner for their efforts in arranging a wonderful day and also the Clark Equipment Co. for an excellent meal.

The meeting was held on the Legion Club veranda. Meeting was opened with a discussion on the meeting dates, which were decided as follows: Monday, September 25th; Monday, October 30th; Monday, November 27th; Monday, December 18th; Monday, January 22nd; Monday, February 26th; Monday, March 26th; Friday, April 27th is to be the date of the annual Spring Symposium; Friday, May 25th meeting is to be in the form of an outing with the ladies invited.

The following are the officers elected for the fiscal year. *Chairman*—Robert E. Kemp, American Seating Co., Grand Rapids, Mich.; *First Vice-Chairman*—Carl Van Loo, Plymouth Road Plant, Rapids Standard Co., Grand Rapids, Mich.; *Second Vice-Chairman*—Robert Kline, Oliver Corp., Battle Creek, Mich.; *Secretary*—Gordon Hill, Aladdin Rod Co., Grand Rapids, Mich.; *Treasuer*—Chet Voorhorst, Purity Cylinder Gases, Grand Rapids, Mich. and *Executive Committee*—2 years—Herbert Knape, Glenn G. Hickock, Paul Wagner, L. J. Harris and Edward Bares, 1 year—William M. McClellan, H. Dale Hoffmeyer and Harvey Wheeler.

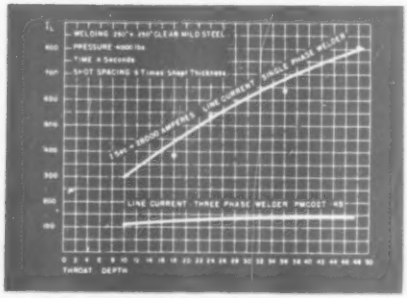
Meeting Western Michigan Section

SCIAKY

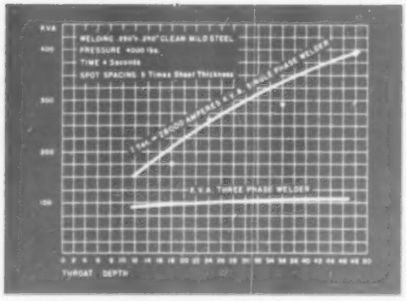
RESISTANCE WELDING

THREE PHASE

1. **Makes it possible for almost any plant to have the benefits of resistance welding regardless of power facility limitations.**
2. Reduces KVA demand 75% or more.
3. Provides balanced load on the power line.


WELDING 250"+.250" CLEAN MILD STEEL
PRESSURE 4000 lbs
TIME 4 Seconds
SPOT SPACING 8 Times Sheet Thickness
LINE CURRENT SINGLE PHASE WELDER
LINE CURRENT THREE PHASE WELDER PWCOOT 40
THROAT DEPTH

Above—Graph showing line current versus throat depth for single-phase and three-phase welders.



Above—Graph indicating ratio of line current of a single-phase welder to the line current of a three-phase welder, and the ratio of KVA single-phase against three-phase.

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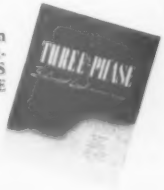

LIST OF NEW MEMBERS

August 1 to August 31, 1950

ANTHONY WAYNE
Busler, Roy. F. (B)
Trump, Golen W. (B)

BIRMINGHAM
Crabtree, Jerome O. (C)
Pogue, R. H. (C)
Woodall, A. M. (C)

CLEVELAND
Ashmus, William (C)
Dreschsler, A. C. (B)
Eberlein, O. H. (B)
Jones, Raymond C. (B)
Kruse, Peter R. (B)
Moore, Joseph J. (C)
Weber, G. K. (B)
Young, L. L. (B)

COLUMBUS
Payne, T. W. (C)

DETROIT
Fielder, Don W. (B)
Reagan, Jeremiah (C)
Waeschle, A. (A)

HOUSTON
Lambrix, Percy J. (B)

LEHIGH VALLEY
Seidler, Edwin H. (B)

LOS ANGELES
Dally, Howard H. (C)
Griffes, Sidney S. (B)

MAHONING VALLEY
Waldo, A. W. (B)

MILWAUKEE
Brumder, H. E. (B)

NEW ORLEANS
Abrahm, M. C. (A)

NEW YORK
Briggs, Robert Wesley (B)

NORTHERN NEW YORK
Abell, R. F. (B)

NORTHWEST
Canfield, N. N. (A)
Roal, Ralph (C)
Spaulding, Roy L. (A)

NORTHWESTERN PA.
Budd, George R. (B)

PITTSBURGH
McKay, James C. (A)

PORTLAND
Howerton, R. L. (B)

PUGET SOUND
Bjornstad, B. Thor (B)

ROCHESTER
Davis, Frank R. (C)
Green, John B. (C)

SAGINAW VALLEY
King, David F. (D)

WASHINGTON
Cartzendafner, Elvin (C)

WICHITA
Moberly, Harry L. (C)

YORK-CENTRAL
Hullman, Charles W. (B)

NOT IN SECTIONS
Kumose, Tomissburo (C)
Naka, Takeo (B)
Pandher, Banta Singh (B)

Members Reclassified

During the month of August

ANTHONY WAYNE
Kirchhifer, Rufus (C to B)

LOS ANGELES
Gasper, Louis W. (C to B)

PITTSBURGH
Doty, W. D'Orville (C to B)

Statement of the Ownership, Management, Circulation, etc.

REQUIRED BY THE ACTS OF CONGRESS OF AUGUST 24, 1912, AS AMENDED BY THE ACTS OF MARCH 3, 1933, AND JULY 2, 1946

OF THE WELDING JOURNAL, published monthly at Easton, Pa., for October 1, 1950.

State of New York
County of New York } ss.

Before me, a Notary Public in and for the State and County aforesaid, personally appeared William Spraragen, who, having been duly sworn according to law, deposes and says that he is the Editor of THE WELDING JOURNAL and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily, weekly, semiweekly or triweekly news paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Acts of March 3, 1933 and July 2, 1946, (section 537, Postal Laws and Regulations) printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:

Name of — Post Office Address

Publisher, American Welding Society, 33 W. 39th St., New York 18, N. Y.
Editor, William Spraragen, 33 W. 39th St., New York 18, N. Y.
Managing Editor, William Spraragen, 33 W. 39th St., New York 18, N. Y.

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.)

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4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the twelve months preceding the date shown above is 10,000 (This information is required from daily, weekly, semiweekly, and triweekly newspapers only.)

WILLIAM SPRARAGEN, Editor.

Sworn to and subscribed before me this 18th day of September, 1950.

FRANCIS J. MOONEY
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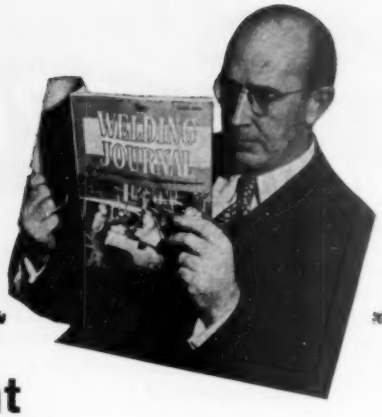

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Supplement to The Welding Journal, October, 1950

Optimum Flash-Welding Conditions for Aluminum Alloys

—the importance of upset variables

Weld strength influenced by peak temperatures at weld line and by temperature gradients. Faster flashing velocities, lower magnitudes of upset current and shorter durations of upset current produce higher weld strengths but required greater upset pressures

by E. F. Nippes, W. F. Savage, J. J. McCarthy and P. Patriarca

SUMMARY

THE results of this investigation indicated that nearly 100% tensile-joint efficiency could be attained by flash welding the alloys 61S-T, 14S-T, 75S-T and 24S-T. A comprehensive study of the peak temperature reached by the metal near the final weld line and the temperature distribution about the final weld line proved helpful in evaluating the optimum welding conditions for these alloys.

Welding variables which increased the peak temperature near the weld line and reduced the steepness of the temperature gradient were found to markedly influence the weld strength. The sensitivity of the alloys studied was found to differ, the alloys in order of decreasing sensitivity to overaging under comparable conditions being, 61S-T, 14S-T, 75S-T and 24S-T. In general, faster flashing velocities, lower magnitudes of upset current and shorter durations of upset current all produce higher weld strengths.

The upset pressure requirements for producing various amounts of upset per specimen up to 1.5 times the section thickness were studied and the influence of welding variables on these requirements investigated. The magnitude of the upset current was found to be the most important variable influencing the upset pressure requirements, and the temperature distribution established during flashing was found to be of significance particularly with the higher strength alloys. In general, slower flashing velocities and larger magnitudes of upset current were found more effective in reducing the upset pressure requirements. It therefore became evident that a compromise in weld properties might have to be made in cases where the upset pressure available for welding larger sections would be the deciding factor. However, significant reduction of from 40–65% in upset pressure requirements was found possible without reducing the tensile joint efficiency by more than 10%, the greatest reductions in pressure requirements being associated with the stronger alloys. With alloy 24S-T it was possible to permit selection of welding conditions such that a 50% reduction in upset pressure could be realized with no decrease in weld properties.

E. F. Nippes, W. F. Savage, J. J. McCarthy and P. Patriarca are associated with the Dept. of Metallurgical Engineering, Rensselaer Polytechnic Inst., Troy, N. Y.

Scheduled for presentation at Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

INTRODUCTION

The previous report[1] on the program involving the flash welding of structural aluminum alloys, was con-

cerned with the study of the variables involved during the flashing part of the welding cycle. In order to establish the importance of the different flashing variables, a study of the temperature distribution back of the flashing interface was undertaken. The investigation described in this report is concerned with a similar study of the variables involved in the flash-welding process after the initiation of upset. In view of the important results obtained by use of temperature distribution studies during the flashing part of the cycle, it was decided also to study the effect of upset variables by means of temperature measurements. As a result of the previous work it was possible to standardize the flashing part of the welding cycle so that the mean temperature of the flashing interface always reached the melting range before the initiation of the upset portion of the welding cycle. It was also possible to produce various temperature distributions back of the flashing interface prior to the initiation of upset.

A preliminary investigation[2] was confined to a study of the effects of upset variables on the strength of flash welds and the upset pressure required. The variables investigated were upset current duration, upset current magnitude and upset distance. The effects of these variables were studied in the alloys 24S-T and 61S-T. The purpose of applying current during the upset portion of the flash welding cycle was to reduce the magnitude of upset pressure required, and thus permit the welding of larger sections with a given size welding machine, and consequent available welding force. Although it could readily be expected that upset current would reduce the required upset force, it was necessary to conduct the investigation in order to determine how much reduction of force could be achieved without undue sacrifice of weld strength due to the overaging effect of the upset current. The results of the preliminary investigation indicated that decreasing the upset current magnitude and duration, increasing the upset distance, and increasing the steepness of the temperature distribution prior to upset, all tended to increase the weld strength. As a consequence of these changes, the upset pressure requirements increased.

Since the preliminary investigation showed that it was possible to use too much additional heat during the upset operation, and thus reduce the weld strength, it was necessary to undertake a more comprehensive study of the effects of the upset variables on weld strength and upset pressure requirements. The present investigation included the more comprehensive study, and was supplemented by a careful study of the upset pressure requirement as a function of time during the upset operation, and also by temperature measurements made during the upsetting operation. The study of upset force required during different portions of the upset operation was particularly significant in establishing the requirements for making satisfactory welds under different conditions of upset current magnitude and duration.

SCOPE

The primary purpose of this investigation was to obtain optimum flash-welding conditions for the various structural aluminum alloys. The majority of the work was done using 61S-T in two section sizes. The effects of flashing velocity, upset current magnitude and upset current duration on weld strength, on upset force and on temperature distribution in the vicinity of the weld were determined. Similar work was carried out to determine the effect of welding variables on 75S-T, 14S-T and 24S-T.

MATERIAL

In order that the results of this investigation might be generally applicable to all of the structural aluminum alloys, 14S-T, 24S-T, 61S-T and 75S-T were used. Welds were made in 61S-T in two section sizes: 0.188 x 1 in. and 0.250 x 1 in. The other alloys, welds were made using 0.250- x 1-in. section sizes. Temperature measurements were made using the 0.250-in. gage, while, in the 61S-T, the temperature measurements were also made using the 0.188-in. gage. All specimens used in this investigation were 6 in. long.

EQUIPMENT

The equipment and instrumentation employed in this research have been previously reported.[3,4]

PROCEDURE AND RESULTS

This section has been divided into four parts entitled:

1. The effect of flash-welding variables on the temperature distribution.
2. The effect of flash-welding variables on the mechanical properties of completed welds.
3. The effect of flash-welding variables on the upset pressure requirements.
4. The effect of the material properties.

In all cases, the flashing velocities specified are actually expressed in terms of instantaneous rate of burn-off at each specimen interface at the instant of upset. Since the time displacement pattern during flashing was parabolic, the average velocity during flashing was equal to one-half the instantaneous velocity.

The contribution of flashing velocity, section size, upset current magnitude and upset current duration is considered under each of the above classifications in order to simplify the rationalization of observed trends. It is thus possible to investigate the thermal cycle experienced by the material being welded, and observe the effect of welding variables upon the nature of this thermal cycle. With the information gained in this way, the effects of welding variables upon the joint performance may be explained on a sound metallurgical

basis. Next the upset pressure requirements may be considered, and certain combinations of variables justified or rejected by upset pressure requirements and the joint performance data.

The alloy 61S-T was employed in the investigative work reported in parts 1–3 above, and therefore further work had to be done in order to make the information gained generally useful. This supplementary work involved the production of welds in three other commercial aluminum alloys; 75S-T, 14S-T, and 24S-T and is reported in the section entitled "The Effect of Material Properties."

THE EFFECT OF FLASH-WELDING VARIABLES ON TEMPERATURE DISTRIBUTION

Flashing Velocity

Figures 1–3 show the temperature distribution in 0.250- x 1-in. specimens of 61S-T at the end of the flashing period for flashing velocities of 0.374, 0.507 and 0.671 in./sec., respectively. The solid curves represent the temperature distribution at the end of flashing, and it should be noted that while the average temperature of the final flashing interface is within the melting range of the alloy in each case, the faster the flashing velocity, the steeper is the temperature gradient. The open circles indicate the satisfactory agreement between the measured temperatures and the gradients as calculated by methods outlined in a previous report.[1] The heavy arrow marked "position of the final weld line" indicated the location, at the end of flashing, of the material which ultimately reaches the final weld line as a result of the upsetting action.

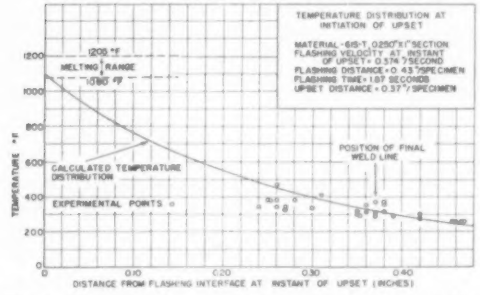
TEMPERATURE DISTRIBUTION AT INITIATION OF UPSET
MATERIAL-61S-T, 0.250" X 1" SECTION
FLASHING VELOCITY AT INSTANT OF UPSET = 0.374"/SECOND
FLASHING DISTANCE = 0.43"/SPECIMEN
FLASHING TIME = 1.87 SECONDS
UPSET DISTANCE = 0.37"/SPECIMEN
1205°F
MELTING RANGE
1080°F
POSITION OF FINAL WELD LINE
CALCULATED TEMPERATURE DISTRIBUTION
EXPERIMENTAL POINTS
TEMPERATURE °F
DISTANCE FROM FLASHING INTERFACE AT INSTANT OF UPSET (INCHES)

Fig. 1 Temperature distribution curves, for 61S-T, 0.250- x 1-in. section, flashing velocity—0.374 in./sec.

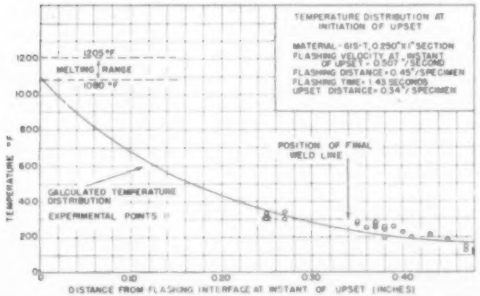
TEMPERATURE DISTRIBUTION AT INITIATION OF UPSET
MATERIAL-61S-T, 0.250" X 1" SECTION
FLASHING VELOCITY AT INSTANT OF UPSET = 0.507"/SECOND
FLASHING DISTANCE = 0.45"/SPECIMEN
FLASHING TIME = 1.43 SECONDS
UPSET DISTANCE = 0.34"/SPECIMEN
1205°F
MELTING RANGE
1080°F
POSITION OF FINAL WELD LINE
CALCULATED TEMPERATURE DISTRIBUTION
EXPERIMENTAL POINTS
TEMPERATURE °F
DISTANCE FROM FLASHING INTERFACE AT INSTANT OF UPSET (INCHES)

Fig. 2 Temperature distribution curves, for 61S-T, 0.250- x 1-in. section, flashing velocity—0.507 in./sec.

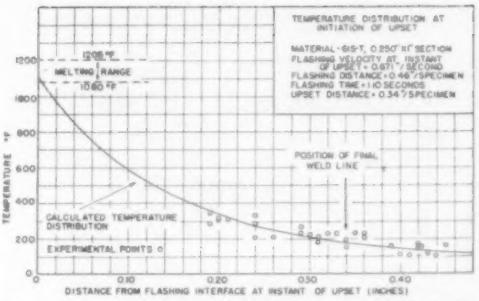
TEMPERATURE DISTRIBUTION AT INITIATION OF UPSET
MATERIAL-61S-T, 0.250" X 1" SECTION
FLASHING VELOCITY AT INSTANT OF UPSET = 0.671"/SECOND
FLASHING DISTANCE = 0.46"/SPECIMEN
FLASHING TIME = 1.0 SECONDS
UPSET DISTANCE = 0.34"/SPECIMEN
1205°F
MELTING RANGE
1080°F
POSITION OF FINAL WELD LINE
CALCULATED TEMPERATURE DISTRIBUTION
EXPERIMENTAL POINTS
TEMPERATURE °F
DISTANCE FROM FLASHING INTERFACE AT INSTANT OF UPSET (INCHES)

Fig. 3 Temperature distribution curves, for 61S-T, 0.250- x 1-in. section, flashing velocity—0.671 in./sec.

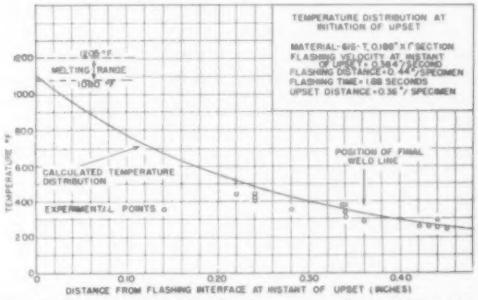
TEMPERATURE DISTRIBUTION AT INITIATION OF UPSET
MATERIAL-61S-T, 0.188" X 1" SECTION
FLASHING VELOCITY AT INSTANT OF UPSET = 0.334"/SECOND
FLASHING DISTANCE = 0.44"/SPECIMEN
FLASHING TIME = 1.88 SECONDS
UPSET DISTANCE = 0.36"/SPECIMEN
1205°F
MELTING RANGE
1080°F
POSITION OF FINAL WELD LINE
CALCULATED TEMPERATURE DISTRIBUTION
EXPERIMENTAL POINTS
TEMPERATURE °F
DISTANCE FROM FLASHING INTERFACE AT INSTANT OF UPSET (INCHES)

Fig. 4 Temperature distribution curves, for 61S-T, 0.188- x 1-in. section, flashing velocity—0.334 in./sec.

Figure 4 compares the calculated temperature gradient and the measured temperatures obtained from welds made in 0.188 x 1 in. 61S-T, and shows that the change in section size has not influenced the temperature distributions.

Upset-Current Magnitude

Information about the average peak temperature attained as a function of welding variables is contained in Figs. 5–7. Figure 5 shows the average peak temperature reached by the material 0.04 in. from the final weld line as a function of upset current magnitude for three different flashing velocities and a current duration of 9.0–9.5 cycles. Each experimental point represents the average of peak temperatures measured for two or more welds made under identical conditions. In order to permit comparison of the temperature rise associated with various amounts of upset current for the different flashing velocities, the temperature, at the end of flashing, of the material which ultimately reaches the point 0.04 in. from the weld line is included for each flashing

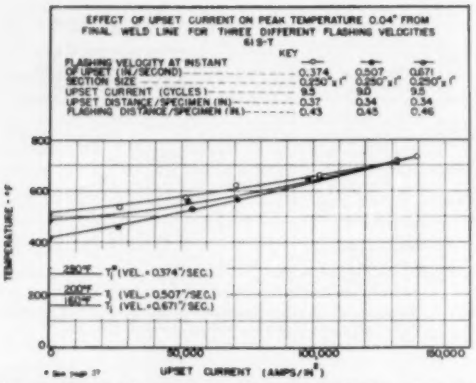

Fig. 5 Effect of upset current on peak temperature for three different flashing velocities

velocity. For example, 280° F., labeled T_i (vel. = 0.374 in./sec.), is the temperature at the end of flashing at a point 0.41 in. from the final flashing interface with a flashing velocity of 0.374 in./sec. as previously reported in Fig. 1. During upset, the material back of the final flashing interface is eliminated as flash, and thus a point initially located 0.41 in. from the final flashing interface ultimately assumes a position 0.04 in. from the final weld line. The difference between the temperature of 280° F., experienced by this material at the end of flashing, and the peak temperature of 510° F., attained at the end of upset when no upset current is employed, represents the contribution of the collapse of the temperature gradient during upset, and heat produced by the internal friction of the material during the plastic deformation produced by upset. Similar behavior may be noted with the other flashing velocities, but it should be noted that the temperature of the material is lower at the termination of flashing due to the steeper temperature gradient associated with the two faster flashing velocities, 0.507 and 0.671 in./sec. The contribution of upset current to the peak temperature attained by a point 0.04 in. from the final weld line may be seen by comparing the peak temperature attained with a given magnitude of upset current with the corresponding peak temperature when no upset current is used. For example, with the fast flashing velocity of 0.671 in./sec., the peak temperature at the end of upset, with an upset current magnitude of 50,000 amp./in.², was 510° F. (lower curve Fig. 5). When no upset current was employed, the peak temperature at the end of the flashing period for the same flashing velocity was 410° F. It may therefore be deduced that 9.5 cycles of 50,000 amp./in² upset current contributed an increase of 510 − 410° F., or 100° F., to the peak temperature attained during upset.

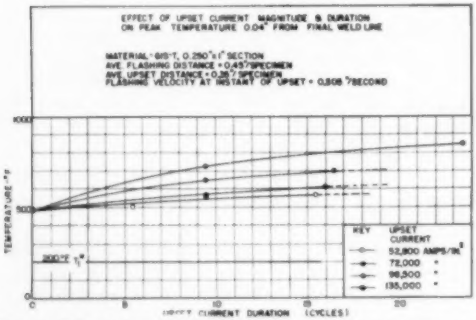
EFFECT OF UPSET CURRENT MAGNITUDE & DURATION ON PEAK TEMPERATURE 0.04" FROM FINAL WELD LINE
MATERIAL: 6I3-T, 0.250"x1" SECTION
AVE. FLASHING DISTANCE = 0.457"/SPECIMEN
AVE. UPSET DISTANCE = 0.25"/SPECIMEN
FLASHING VELOCITY AT INSTANT OF UPSET = 0.505"/SECOND
TEMPERATURE - °F
200°F T_i
KEY
UPSET CURRENT
52,800 AMPS/IN.²
72,000 "
98,500 "
135,000 "
UPSET CURRENT DURATION (CYCLES)

Fig. 6 Effect of upset-current magnitude and duration on peak temperature

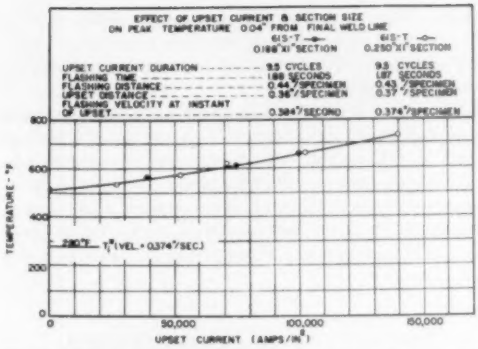

Fig. 7 Effect of upset current and section size on peak temperature

It should be noted also that as the magnitude of upset current increases the peak temperature attained is less dependent on the flashing velocity, that is on the temperature gradient prior to upset. This may be seen by noting that the plots of observed peak temperatures for the three different flashing velocities tend to converge to a point at 135,000 amp./in.²

Upset-Current Duration

Figure 6 shows the effect of upset-current duration on the peak temperature attained at a distance 0.04 in. from the final weld line, for the medium flashing velocity of 0.505 in./sec. As would be expected, the upset current magnitude is approximately twice as effective in raising the peak temperature as is the duration of the upset current. For example, with 52,800 amp./in.², doubling the duration from 8 to 16 cycles results in an added increase of 40° F. in the peak temperature (530° F. for 8 cycles vs. 570° F. for 16 cycles). On the other hand, almost doubling the magnitude of upset current to 98,500 amp./in.², but holding the duration constant at 8 cycles, results in an added increase of 90° F. in the peak temperature (530° F. for 8 cycles of 52,800 amp./in.² vs. 620° F. for 8 cycles of 98,500 amp./in.²).

Section Size

It was previously shown[1] that the temperature gradient established during flashing was independent of section size, and a sample study during this investiga-

tion confirmed this finding. Figure 7 shows that the peak temperature attained at the end of upset is also independent of section size. In this figure, the peak temperature data for two different section sizes are plotted as a function of the upset current magnitude for the same order of flashing velocity, flashing time, upset distance and the same upset-current duration. Since the data fall on the same curve, within the experimental error, it may be concluded that section size has no effect on peak temperature at the end of upset.

THE EFFECT OF FLASH WELDING VARIABLES ON MECHANICAL PROPERTIES OF COMPLETED WELDS

Flashing Velocity and Upset Current

Welds were made at three different flashing velocities using current magnitudes of zero to 140,000 amp./in.^{2} during upset. The current duration was maintained constant at 9–9.5 cycles and the magnitude adjusted by means of phase control.

Tensile specimens for the determination of weld strength were milled to final dimensions of 0.75 x 0.150 x 6 in. with the weld located in the center of the specimen. The results of the tensile tests are shown in Fig. 8. Tensile strengths in per cent of the original strength of the 61S-T, (47,200 psi.) are plotted as a function of the upset-current density for three different flashing velocities. It may be noted that the faster flashing velocities produced welds of superior strength under equivalent conditions of upset current. This is particularly evident at the higher values of upset current where the existence of steeper temperature gradients, associated with the faster velocities, contribute less to the overaging than do the more gradual temperature gradients, associated with the slower velocities. Since the peak temperatures shown previously in Fig. 5, are very nearly the same, regardless of flashing velocity with the large magnitudes of upset current, the only logical explanation for the superior weld properties observed in the case of high-flashing velocities lies in the shorter times at temperature associated with the collapse of the steeper temperature gradient. This is understandable, since the rate of heat flow in a body is more rapid the greater is the temperature gradient. The faster flashing velocities, having been previously shown to cause steeper temperature gradients would therefore cause the heat to flow out of the region of the final weld line more rapidly.

As may be seen from Fig. 8, at the lower values of upset current, below 60,000 amp./in.^{2}, the effect is less marked, and in fact, little significant difference in the weld strength is to be noted below about 70,000 amp./in.^{2} of upset current. By reference to Fig. 5, it may be noted that this upset current magnitude corresponds to a peak temperature of approximately 600° F., 0.04 in. from the final weld line.

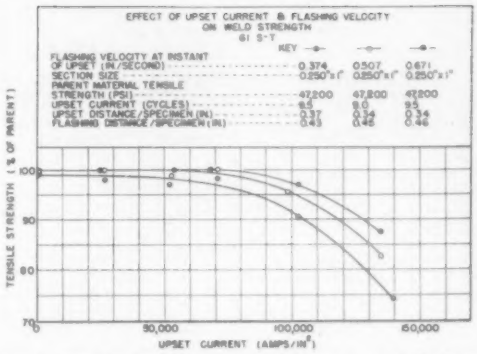

Fig. 8 Tensile strength vs. upset current for 61S-T, three velocities

Upset-Current Duration

Welds were made using upset-current durations of approximately 5, 15 and 24 cycles of upset current, and current densities of from 52,800 to 135,000 amp./in.^{2}, in order to determine the effect of upset current duration on the weld strength. The results of tensile tests of these welds, together with the values previously determined for no upset current and for 9.5 cycles of upset current, are shown in Fig. 9. The tensile strengths in per cent of the parent strength (47,200 psi.) are plotted as a function of upset-current duration, for each current density. It may be noted that for current densities of 52,800 amp./in.^{2}, no appreciable loss in strength due to overaging was observed, even with 24 cycles of upset current. However, as the magnitude of upset current is increased, less time was required for loss of strength due to overaging to become evident. Current densities above 72,000 amp./in.^{2} caused a noticeable decrease in strength when durations in excess of 10 cycles were employed. At a current density of 135,000 amp./in.^{2} the overaging appeared even with short upset-current durations, with an accompanying loss in strength. By reference to Fig. 6, it may be noticed that upset-current magnitudes and durations which cause a loss in strength correspond to a peak temperature of 600° F. or more.

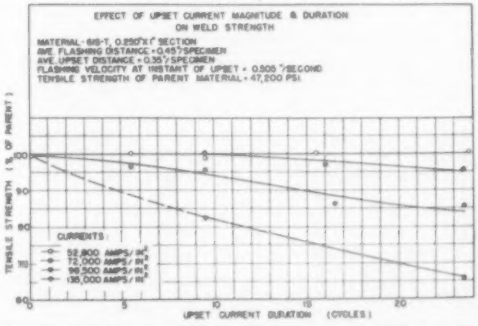

Fig. 9 Tensile strength vs. upset-current duration for various current magnitudes

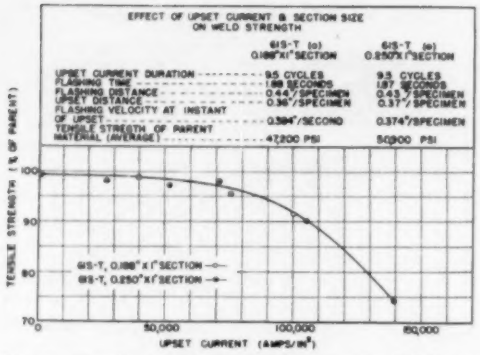
EFFECT OF UPSET CURRENT & SECTION SIZE ON WELD STRENGTH
61S-T (a) 0.188"x1" SECTION
61S-T (a) 0.250"x1" SECTION
UPSET CURRENT DURATION - 9.5 CYCLES
FLASHING TIME - 1.99 SECONDS
FLASHING DISTANCE - 0.44"/SPECIMEN
UPSET DISTANCE - 0.36"/SPECIMEN
FLASHING VELOCITY AT INSTANT OF UPSET - 0.384"/SECOND
TENSILE STRENGTH OF PARENT MATERIAL (AVERAGE) - 47,200 PSI
9.5 CYCLES
1.87 SECONDS
0.43"/SPECIMEN
0.37"/SPECIMEN
0.374"/SPECIMEN
50,900 PSI
TENSILE STRENGTH (% OF PARENT)
61S-T, 0.188" x 1" SECTION
61S-T, 0.250" x 1" SECTION
UPSET CURRENT (AMPS/in²)

Fig. 10 Tensile strength vs. upset current for 61S-T, two section sizes

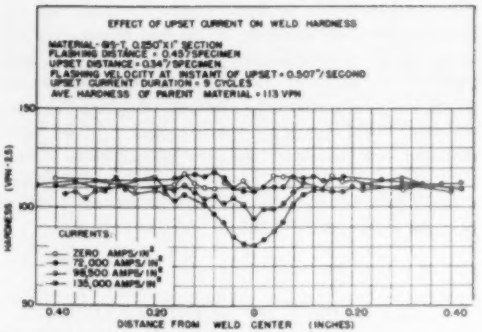
EFFECT OF UPSET CURRENT ON WELD HARDNESS
MATERIAL - 61S-T, 0.250"x1" SECTION
FLASHING DISTANCE = 0.43"/SPECIMEN
UPSET DISTANCE = 0.34"/SPECIMEN
FLASHING VELOCITY AT INSTANT OF UPSET = 0.507"/SECOND
UPSET CURRENT DURATION = 9 CYCLES
AVE. HARDNESS OF PARENT MATERIAL = 113 VPN
CURRENTS:
ZERO AMPS/in²
72,000 AMPS/in²
99,500 AMPS/in²
135,000 AMPS/in²
HARDNESS (VPN-25)
DISTANCE FROM WELD CENTER (INCHES)

Fig. 12 Hardness traverses for 61S-T, 0.250- x 1-in. section, flashing velocity—0.507-in./sec.

Section Size

A series of welds were made using 61S-T in the 0.188 x 1 in. section to determine the effect of the upset variables on weld strength for various section sizes. The welding conditions used were approximately the same as those used for 0.250- x 1-in. gage. The temperature distribution existing in the specimens at the instant of upset has been shown previously in Fig. 4. A previous investigation[1] showed that the temperature distribution caused by flashing was independent of section size within the limits investigated, as may be seen by comparison of Figs. 3 and 6.

The results of the tensile tests of 0.188- x 1-in. specimens are shown in Fig. 10 along with those of the comparable conditions using the 61S-T in the 0.250- x 1-in. section. It may be noted that the effect of upset current on weld strength was also found to be independent of the section size.

In a previous report[2] it was stated that higher strengths could be obtained in the thinner gages than in the thicker gages under identical conditions of upset current and upset distance. While this is true in cases where the upset distance is less than 1.5 times the gage thickness of the thicker specimen, when sufficient upset is utilized to prevent inclusion of oxidized material, the strengths are identical. This is verified by the agreement shown in Fig. 10 for weld strength in the two gages studied, since the values of weld strength as a function of upset current lie on the same curve for both section sizes.

Hardness Measurements

The extent of overaging due to the effect of the different temperature gradients established by the three flashing velocities, and to the additional contribution of the upset current may be more readily observed in Figs. 11–13. Hardness measurements were made at intervals of 0.020 in. in a direction perpendicular to the weld interface, using a Vickers hardness tester with a $2^1/_2$-kg. load. The hardness traverses for the welds made with flashing velocities of 0.374, 0.507 and 0.671 in./sec. are shown in Figs. 11, 12 and 13, respectively. It may be noted from these figures that, for current densities of less than 70,000 amp./in.^{2}, no appreciable softening due to overaging has occurred. It may be seen that, with current densities above 70,000 amp./in.^{2}, both the width of the softened, overaged region and the extent of softening vary directly as the upset current for a given flashing velocity. Furthermore, comparison of Figs. 11–13, reveals that the width of the softened, overaged

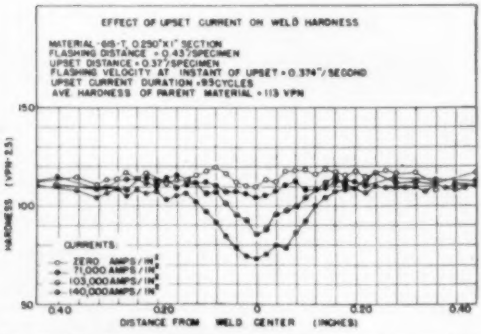
EFFECT OF UPSET CURRENT ON WELD HARDNESS
MATERIAL - 61S-T, 0.250"x1" SECTION
FLASHING DISTANCE = 0.43"/SPECIMEN
UPSET DISTANCE = 0.37"/SPECIMEN
FLASHING VELOCITY AT INSTANT OF UPSET = 0.374"/SECOND
UPSET CURRENT DURATION = 9.5 CYCLES
AVE. HARDNESS OF PARENT MATERIAL = 113 VPN
CURRENTS:
ZERO AMPS/in²
71,000 AMPS/in²
103,000 AMPS/in²
140,000 AMPS/in²
HARDNESS (VPN-25)
DISTANCE FROM WELD CENTER (INCHES)

Fig. 11 Hardness traverses for 61S-T, 0.250- x 1-in. section, flashing velocity—0.374 in./sec.

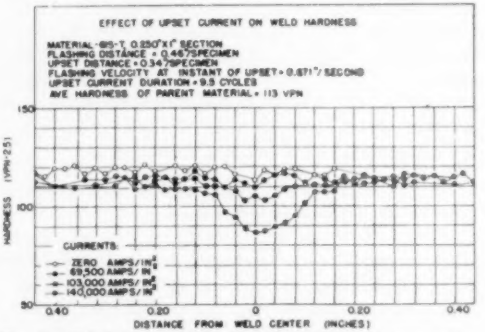
EFFECT OF UPSET CURRENT ON WELD HARDNESS
MATERIAL - 61S-T, 0.250"x1" SECTION
FLASHING DISTANCE = 0.46"/SPECIMEN
UPSET DISTANCE = 0.34"/SPECIMEN
FLASHING VELOCITY AT INSTANT OF UPSET = 0.671"/SECOND
UPSET CURRENT DURATION = 9.5 CYCLES
AVE. HARDNESS OF PARENT MATERIAL = 113 VPN
CURRENTS:
ZERO AMPS/in²
69,500 AMPS/in²
103,000 AMPS/in²
140,000 AMPS/in²
HARDNESS (VPN-25)
DISTANCE FROM WELD CENTER (INCHES)

Fig. 13 Hardness traverses for 61S-T, 0.250- x 1-in. section, flashing velocity—0.671 in./sec.

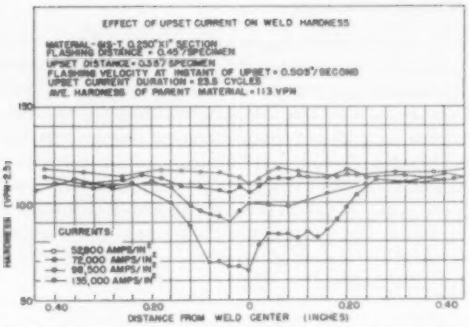

Fig. 14 Hardness traverses for 61S-T, 0.250- x 1-in. section, flashing velocity—0.505 in./sec., upset-current duration 23.5 cycles

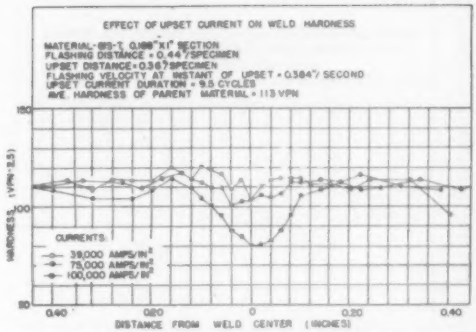

Fig. 15 Hardness traverses for 61S-T, 0.188- x 1-in. section, flashing velocity—0.384 in./sec.

region decreases with increasing flashing velocity, and that the extent of overaging is somewhat less for equivalent current densities with the faster flashing velocities. For example, with a flashing velocity of 0.374 in./sec. and an upset current of 140,000 amp./in.², the softening due to overaging is evident 0.16 in. on either side of the weld line, and the minimum hardness, occurring at the weld center line, was approximately VPN 73. With flashing velocities of 0.671 in./sec. and 140,000 amp./in.², upset current, the overaged region extended only about 0.11 in. on either side of the weld line, and the minimum observed hardness was about VPN 85. This is in agreement with the observed values of tensile strength, and results from the more favorable temperature distribution associated with the faster flashing velocity.

Hardness traverses showing the effect of 23.5 cycles upset-current duration at various current densities are shown in Fig. 14. Extensive overaging is evident in the 0.250- x 1-in. gage 61S-T with values of upset current density of 98,500 amp./in.², and above. All welds included in this figure were made using a medium flashing velocity of 0.505 in./sec./specimen, and may therefore, be compared with Fig. 12 to show the marked effect of the increased upset current duration. It will be noted that both the width of the overaged zone, and the extent of softening are increased appreciably by the longer upset current duration.

The hardness traverses for the 61S-T 0.188- x 1-in. section are presented in Fig. 15. The traverses indicate that severe overaging did not occur until upset-current magnitudes greater than 75,000 amp./in.² were used.

THE EFFECT OF FLASH WELDING VARIABLES ON UPSET-PRESSURE REQUIREMENTS

As the temperature of aluminum alloys is increased a sharp decrease in the compressive strength occurs over a range of temperatures characteristic of the particular alloy. The utilization of this principle as a means of reducing the upset pressure required to produce a desired amount of upset has been thoroughly investigated. The results of this investigation are discussed below, showing the effects of the following variables on upset-pressure requirements:

1. The flashing velocity.
2. The clamping distance.
3. The duration of upset current.
4. The magnitude of upset current.

The following discussion of the above variables is based upon preliminary work involving flash welding of 61S-T. A discussion of the results of similar work involving three other higher strength alloys, namely 14S-T, 24S-T and 75S-T, will be found in the next section.

In all cases the curves plotted represent the average of values measured for at least two separate welds made under identical conditions. In the interest of readability the location of experimental points was omitted, and the curves obtained from plotting these points were collected into significant groups in order to show the effect of important variables.

Flashing Velocity

The flashing velocity has been shown previously to influence the temperature gradient established during flashing. In general, high flashing velocities produce steeper temperature gradients than do lower flashing velocities. That is, the higher the flashing velocity, the more localized is the heating of the stock about the flashing interface.

A steep temperature gradient is desirable from the standpoint of elimination of overaged material from the vicinity of the weld, since, theoretically, this would permit removal of all overaged material as flash by utilizing a sufficient amount of upset. Steep temperature gradients are, however, usually impractical when dealing with the higher strength alloys, since the high upset pressure then required to produce a desired amount of upset is often prohibitive.

The effect of flashing velocity on the upset-pressure requirements may be seen by examination of Fig. 16, which shows the upset-pressure requirements for producing a given amount of upset in 61S-T, plotted as a function of upset distance for three different flashing

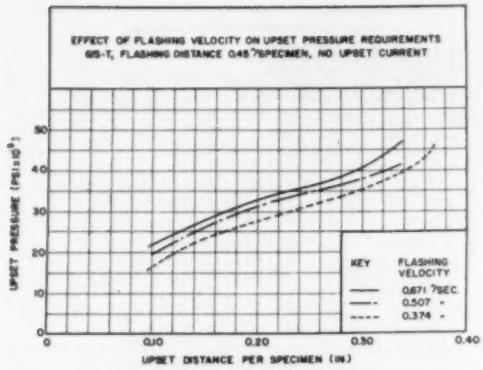
EFFECT OF FLASHING VELOCITY ON UPSET PRESSURE REQUIREMENTS
61S-T, FLASHING DISTANCE 0.45"/SPECIMEN, NO UPSET CURRENT
UPSET PRESSURE (PSI x 10³)
UPSET DISTANCE PER SPECIMEN (IN.)
KEY FLASHING VELOCITY
0.671 "/SEC.
0.507 "
0.374 "

Fig. 16 Effect of flashing velocity on upset-pressure requirements, 61S-T, no upset current

velocities. In all three cases no upset current was employed, and a reduction of up to 20% may be realized in upset-pressure requirements by utilizing a flashing velocity of 0.373 in./sec. instead of the fast velocity of 0.670 in./sec. The reduction in upset-pressure requirements is a direct result of the more general decrease in compressive strength in the material back of the flashing interface. This, in turn, results from the fact that the shallower temperature gradient allows more material to be heated sufficiently to reduce the compressive strength.

Figure 17 illustrates the greater reduction in upset pressure requirements made possible by the use of upset currents, and also indicates that the faster velocities still require higher upset pressures to produce the same amount of upset. In this figure upset currents of 135,000 amp./in.^{2} were employed, which in 61S-T, resulted in a reduction in weld strength due to overaging of 26% with the slow flashing velocity, and 13% with the fast flashing velocity, but permitted as much as 75% reduction in the upset-pressure requirements with the slow velocity, and 50% with the fast. A more complete discussion of the effects of upset currents on upset-pressure requirements will be found in a later section.

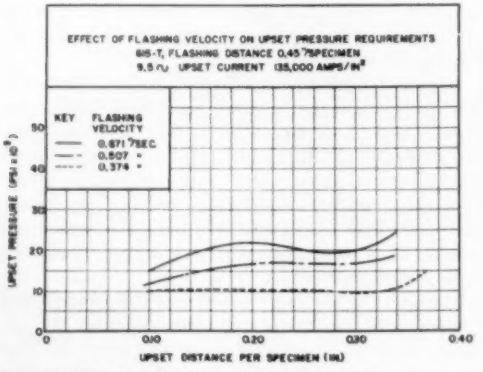
EFFECT OF FLASHING VELOCITY ON UPSET PRESSURE REQUIREMENTS
61S-T, FLASHING DISTANCE 0.45"/SPECIMEN
9.5 Ω UPSET CURRENT (135,000 AMPS/IN²)
UPSET PRESSURE (PSI x 10³)
UPSET DISTANCE PER SPECIMEN (IN.)
KEY FLASHING VELOCITY
0.671 "/SEC.
0.507 "
0.374 "

Fig. 17 Effect of flashing velocity on upset-pressure requirements, 61S-T, 135,000 amp./in.^{2}

Clamping Distance

The initial clamping distance is important in controlling the temperature gradient, since it determines the distance from the flashing interface to the jaws of the flash welds, i.e., the low-temperature heat reservoir. In general, sufficient initial clamping distance must be employed to insure that the temperature gradient is continuous all the way to the low-temperature reservoir at the jaws. If too small an initial clamping distance is employed, the temperature distribution may become distorted and a steeper temperature gradient results at the end of flashing.

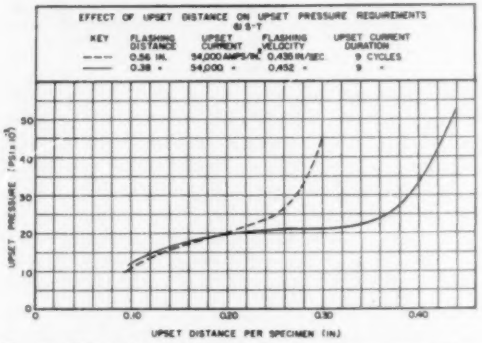
EFFECT OF UPSET DISTANCE ON UPSET PRESSURE REQUIREMENTS
61S-T
KEY FLASHING DISTANCE UPSET CURRENT FLASHING VELOCITY UPSET CURRENT DURATION
0.56 IN. 54,000 AMPS/IN² 0.436 IN./SEC. 9 CYCLES
0.38 " 54,000 " 0.452 " 9 "
UPSET PRESSURE (PSI x 10³)
UPSET DISTANCE PER SPECIMEN (IN.)

Fig. 18 Effect of upset distance on upset-pressure requirements, 61S-T

Figure 18 shows the effect of upset distance on the pressure requirements, and shows the influence of the final clamping distance in both cases. It will be noted the pressure requirements for upset distances of up to 0.20 in./specimen are the same in both cases, one weld having a greater burn-off distance, but the same initial clamping distance and flashing velocity as the other. However, the dashed curve shows a rapid increase in pressure requirement for upset distances greater than 0.20 in. with the weld having the greater flashing distance. This reflects the fact that, when a greater burn-off is employed with the same initial clamping distance, interference with the upsetting action results sooner because of the smaller amount of free space between the jaws during upset. In the case of the solid curve which shows the upset pressure requirements for an identical weld in every respect except burn-off distance, the upsetting action could be continued much further before the problem of jaw interference was encountered. The sharp increase in upset pressures is, in part, caused in both cases by the proximity of the heat sink to the weld interface. The jaws of the welder being only about 0.15 in. from the weld interface at the completion of upset in both cases, heat is rapidly removed from the material being upset, thus reducing its temperature and increasing its compressive strength. In the case of the weld having a maximum upset distance of 0.48 in. the jaws of the welder are located farther from the final flashing interface, and the sharp rise in upset-pressure

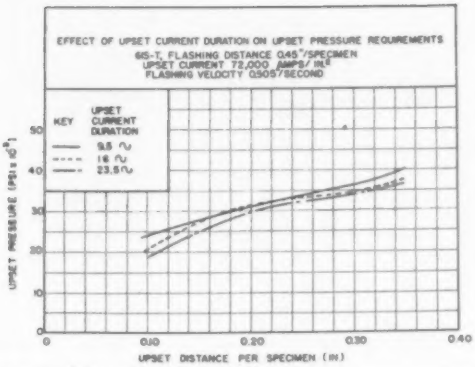
EFFECT OF UPSET CURRENT DURATION ON UPSET PRESSURE REQUIREMENTS
61S-T, FLASHING DISTANCE 0.45"/SPECIMEN
UPSET CURRENT 72,000 AMPS/ IN.²
FLASHING VELOCITY 0.505"/SECOND
KEY UPSET CURRENT DURATION
9.5 ∿
16 ∿
23.5 ∿
UPSET PRESSURE (PSI x 10³)
UPSET DISTANCE PER SPECIMEN (IN.)

Fig. 19 Effect of upset-current duration on upset-pressure requirements, 61S-T, 72,000 amp./in.²

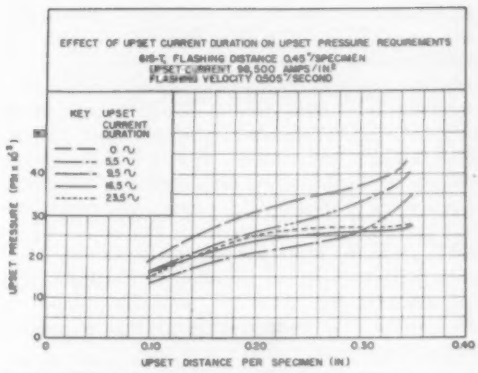

Fig. 20 Effect of upset-current duration on upset-pressure requirements, 61S-T, 98,500 amp./in.²

requirement is delayed until nearly 0.40 in. of upset has occurred, thus bringing the weld interface again near to the low-temperature reservoir provided by the jaws.

Other factors contributing to the abrupt increase in force requirements are:

1. Interference with the upsetting action by the limited amount of space between the jaws when upsetting is carried on up to very short final clamping distances.
2. The effective increase in cross-sectional area produced by the production of upset material as flash.

Increasing the initial clamping distance would reduce the heat loss to the jaws, and reduce the interference with the upsetting action, but has little effect on the increase in area of the specimen during upset.

Upset-Current Duration

One method of reducing the compressive strength of the material during the upset portion of a flash-welding operation is to raise the temperature of the metal by the use of upset current. The duration of the upset current was found to have little effect on the compressive strength during upset when upset currents of less than 100,000 amp./in.² were employed. This may be seen by examination of Fig. 19 which shows the variation in upset-pressure requirements for various upset distances, with upset currents of 72,000 amp./in.² for durations up to 25 cycles. No significant trend can be observed with the possible exception of an approximate 10% decrease with the longer current durations represented in this figure.

With larger current magnitudes, e.g., 98,500 amp./in.², a significant decrease in pressure requirements may be observed with increase in upset current duration up to 10 cycles, and less consistent decrease with still longer durations for the large amounts of upset as shown in Fig. 20. It was, however, found impractical to utilize more than 10 cycles in most instances, because of the increase in overaging observed, and the accompanying loss of strength in the completed weld.

The observed trends, therefore, indicate that upset-current magnitudes of less than 100,000 amp./in.² are insufficient to raise the temperature of the 61S-T enough to realize the sharp decrease in compressive strength, as were also currents of 100,000 amp./in.² for durations less than 10 cycles. It appears, however, that if completed weld strengths of 96% of original parent strength may be tolerated in 61S-T, an increase of approximately 33% in machine capacity may be realized by the use of upset current. This may be seen by reference to Figs. 9 and 20 for welding conditions involving an upset-current magnitude of 98,500 amp./in.² for 9.5 cycles. These welding conditions correspond to a peak temperature of approximately 650° F., at a distance 0.04 in. from the final weld line, as shown previously in Fig. 5.

Upset-Current Magnitude

One of the most important variables influencing the upset pressure requirements is the magnitude of upset current. Figure 21, shows the variation in upset pressure requirements for various upset distances, plotted for five different upset currents with a duration of 9.5 cycles. The data presented were obtained using a flash-

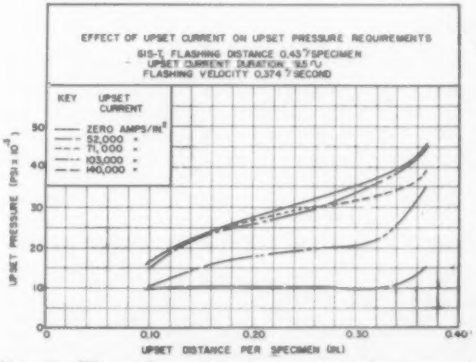

Fig. 21 Effect of upset-current magnitude on upset-pressure requirements, 61S-T

ing velocity of 0.374 in./sec. with 61S-T, but similar data were obtained for other flashing velocities. It should be noted that current magnitudes of up to 71,000 amp./in.^{2} produced only a slight decrease in the force requirements, whereas currents of 103,000 and 140,000 amp./in.^{2} showed reductions in required upset pressure of 50 and 75%, respectively. It should be recognized, however, that reductions in tensile strength of the completed welds of 10 and 25%, respectively, result from such practice, as shown previously in Fig. 8. In the 61S-T alloys this is probably not too serious since it is rarely employed in structures where very high strengths are required, and, therefore, the large increase in machine capacity made possible by this decrease in weld strength might well be justifiable.

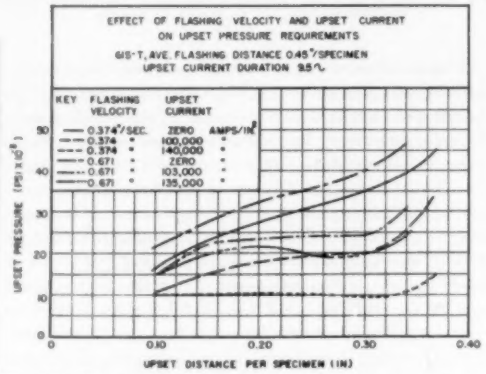
EFFECT OF FLASHING VELOCITY AND UPSET CURRENT
ON UPSET PRESSURE REQUIREMENTS
6IS-T, AVE. FLASHING DISTANCE 0.45"/SPECIMEN
UPSET CURRENT DURATION 9.5 ∿
KEY FLASHING VELOCITY UPSET CURRENT
0.374"/SEC. ZERO AMPS/IN²
0.374 " 100,000 "
0.374 " 140,000 "
0.671 " ZERO "
0.671 " 103,000 "
0.671 " 135,000 "
UPSET PRESSURE (PSI) X 10³
UPSET DISTANCE PER SPECIMEN (IN.)

Fig. 22 Effect of flashing velocity and upset current on upset-pressure requirements, 61S-T

A summary of the effects of flashing velocity and upset current may be seen in Fig. 22 where upset-pressure requirements are again plotted as a function of upset distance for 61S-T. It should be noted that the effect of flashing velocity is not obscured by the application of upset current, but rather is accentuated, since the difference in upset pressure requirements for the two different velocities is more pronounced at the higher magnitudes of upset current.

Section Size

Figure 23 shows the effect of section size on the upset-pressure requirements. It may be noted that for two welds made with equivalent conditions in 0.188 and 0.250 in., thick 61S-T, the upset-pressure requirements are the same within the limits of accuracy of measurement.

THE EFFECT OF MATERIAL PROPERTIES

By utilizing the information gained from this investigation of 61S-T, it was possible to investigate the influence of variables on the flash welding of other aluminum alloys with considerably less experimental work. The following section presents a summary of the

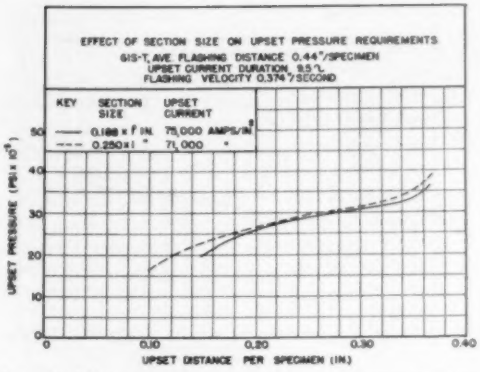
EFFECT OF SECTION SIZE ON UPSET PRESSURE REQUIREMENTS
6IS-T, AVE. FLASHING DISTANCE 0.44"/SPECIMEN
UPSET CURRENT DURATION 9.5 ∿
FLASHING VELOCITY 0.374"/SECOND
KEY SECTION SIZE UPSET CURRENT
0.188 x 1" IN. 75,000 AMPS/IN²
0.250 x 1 " 71,000 "
UPSET PRESSURE (PSI x 10³)
UPSET DISTANCE PER SPECIMEN (IN.)

Fig. 23 Effect of section size on upset-pressure requirements, 61S-T

findings resulting from the investigation with other alloys. Since it was found that the production of flash welds having tensile strengths equal to the original strength of the parent material with 24S-T was readily accomplished, some of the temperature studies were eliminated for this alloy.

The alloys 75S-T and 14S-T are considered simultaneously in the first part of this section. The results of the work on 24S-T is considered separately at the end of this section, since it behaved quite differently from 75S-T and 14S-T.

Temperature Distribution for 75S-T and 14S-T

Figures 24 and 25 show the temperature distribution at the end of flashing in 75S-T and 14S-T for flashing velocities of 0.498 and 0.490 in./sec., respectively. The 14S-T, having very nearly the same thermal and electrical conductivity as 61S-T, exhibits a temperature distribution at the end of flashing similar to that exhibited by 61S-T under comparable conditions. The 75S-T having lower thermal and electrical conductivity, exhibits a steeper temperature gradient as would be expected. The principal difference in the temperature distribution exhibited by 61S-T and 14S-T, arises from the

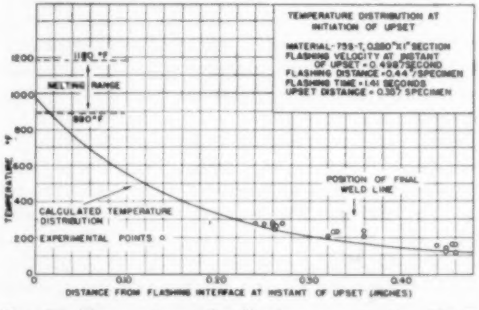

Fig. 24 Temperature distribution curves, for 75S-T, 0.250- x 1-in. section, flashing velocity—0.498 in./sec.

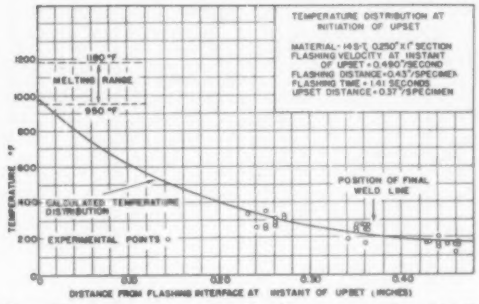
TEMPERATURE DISTRIBUTION AT INITIATION OF UPSET
MATERIAL - 14S-T, 0.250" x 1" SECTION
FLASHING VELOCITY AT INSTANT OF UPSET = 0.490"/SECOND
FLASHING DISTANCE = 0.43"/SPECIMEN
FLASHING TIME = 1.61 SECONDS
UPSET DISTANCE = 0.37"/SPECIMEN
1190 °F
MELTING RANGE
950 °F
CALCULATED TEMPERATURE DISTRIBUTION
EXPERIMENTAL POINTS
POSITION OF FINAL WELD LINE
TEMPERATURE °F
DISTANCE FROM FLASHING INTERFACE AT INSTANT OF UPSET (INCHES)

Fig. 25 Temperature distribution curves, for 14S-T, 0.250- x 1-in. section, flashing velocity—0.490 in./sec.

lower melting range possessed by 14S-T, which lowers the temperature gradient over its entire length.

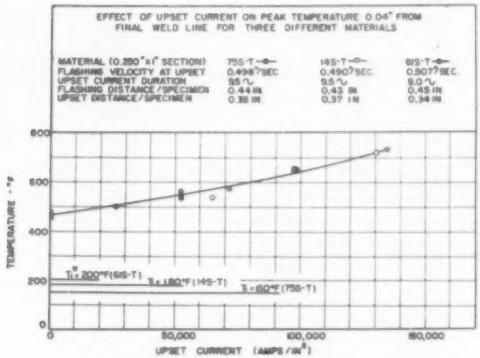

Fig. 26 Effect of upset current on peak temperature for 75S-T, 14S-T and 61S-T

In spite of differences existing in the temperature gradients for 75S-T and 14S-T, the peak temperature attained at a distance 0.04 in. from the final weld line was essentially the same. Figure 26 illustrates this fact by combining the peak temperature data for 75S-T, 14S-T and 61S-T in a single plot as a function of upset current magnitude. Although the temperature, T_f, at the end of flashing, of the material which ultimately reaches the weld zone differs in each case, other differences just by coincidence balance the over-all heating effects in the three alloys. The added strength of the 14S-T, and the added strength and electrical resistance of the 75S-T tend to produce slightly greater heating effects during the upset period. Therefore, although the temperature of the material which ultimately reaches the weld line is lower for 14S-T (180° F.) and still lower for 75S-T (150° F.) at the instant upset starts, the final temperatures tend to approximate the same value as does 61S-T under identical welding conditions.

Mechanical Properties of 75S-T and 14S-T

Figure 27 compares the effect of upset current on the

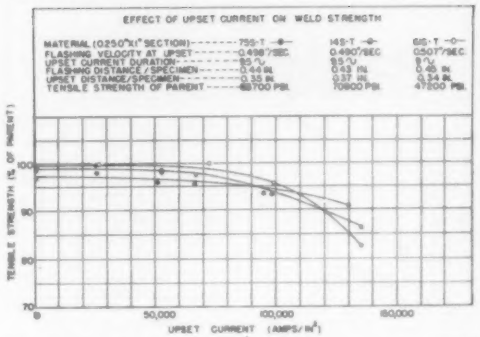

Fig. 27 Tensile strength vs. upset current for 75S-T 14S-T and 61S-T

mechanical properties of completed flash welds in 75S-T, 14S-T and 61S-T made holding all other welding conditions the same. Two significant trends may be observed on this plot. First, with the low values of upset current, below 70,000 amp./in.², the 61S-T shows the greatest per cent of parent strength, the 14S-T next and the 75S-T the lowest per cent of parent strength, being of the order 99.5, 99 and 97%, respectively. Second, with upset current magnitudes of 130,000 amp./in.² the above order is exactly reversed, the strengths in per cent of parent strength being, 91% for 75S-T, 87.5% for 14S-T and 85% for 61S-T.

The following explanation is advanced for this phenomenon. At peak temperatures below 600° F., such as are experienced with upset currents of less than 70,000 amp./in.² (see Fig. 26), the 75S-T and 14S-T exhibit greater resistance to deformation than does 61S-T and thus make the upsetting action more difficult. The tendency being for the forging action of upset to be distributed over a larger volume of material in the higher strength alloys, it was more difficult to obtain welds having 100% of original parent strength. However, since 61S-T is the most susceptible to overaging, 14S-T next and 75S-T least, with the greater upset-current magnitudes the situation was reversed. The peak temperatures being the same for all three alloys, the alloy least susceptible to overaging, 75S-T, would be expected to exhibit the highest weld strength, and the one exhibiting the greatest susceptibility, 61S-T, the lowest weld strength, as is the case with 130,000 amp./in.²

Figures 28 and 29 show hardness traverses for welds made in 75S-T and 14S-T, respectively, with various amounts of upset current, other variables being comparable. It is significant to notice that the reduction in hardness occurs over a wider region in the 75S-T than in the 14S-T. For example with 135,000 amp./in.² the softened region in 75S-T extends nearly 0.56 in., whereas with 14S-T under the same conditions it only extends 0.36 in. This is believed to result from the difference in workability shown by the two alloys. A comparison of the percentage reduction in hardness in the two alloys under comparable welding conditions reveals results similar to those exhibited by the tensile strengths. The

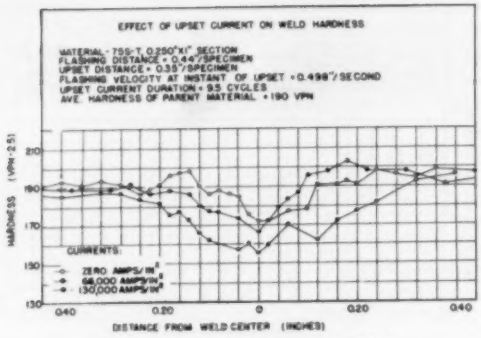
EFFECT OF UPSET CURRENT ON WELD HARDNESS
MATERIAL - 75S-T, 0.250" X 1" SECTION
FLASHING DISTANCE = 0.44"/SPECIMEN
UPSET DISTANCE = 0.35"/SPECIMEN
FLASHING VELOCITY AT INSTANT OF UPSET = 0.498"/SECOND
UPSET CURRENT DURATION = 9.5 CYCLES
AVE. HARDNESS OF PARENT MATERIAL = 190 VPN
CURRENTS:
ZERO AMPS/IN.²
98,000 AMPS/IN.²
130,000 AMPS/IN.²
HARDNESS (VPN - 2.5)
DISTANCE FROM WELD CENTER (INCHES)

Fig. 28 Hardness traverses for 75S-T

75S-T shows a maximum reduction in hardness with 130,000 amp./in.² upset current of 34 VPN, or a 17.9% decrease, whereas the 14S-T shows a reduction of 30 VPN, or a 20% decrease. The 61S-T, on the other hand, shows a reduction of approximately 30 VPN from a maximum of 110 VPN under similar conditions, or about a 27.5% reduction. This is in qualitative agreement with the tensile data for the same welds in the three alloys, as discussed previously in Fig. 27.

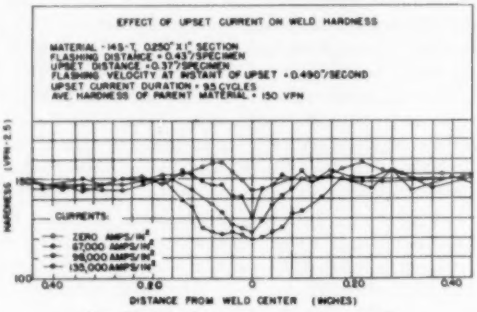
EFFECT OF UPSET CURRENT ON WELD HARDNESS
MATERIAL - 14S-T, 0.250" X 1" SECTION
FLASHING DISTANCE = 0.43"/SPECIMEN
UPSET DISTANCE = 0.37"/SPECIMEN
FLASHING VELOCITY AT INSTANT OF UPSET = 0.490"/SECOND
UPSET CURRENT DURATION = 9.5 CYCLES
AVE. HARDNESS OF PARENT MATERIAL = 150 VPN
CURRENTS:
ZERO AMPS/IN.²
67,000 AMPS/IN.²
98,000 AMPS/IN.²
135,000 AMPS/IN.²
HARDNESS (VPN - 2.5)
DISTANCE FROM WELD CENTER (INCHES)

Fig. 29 Hardness traverses for 14S-T

Upset Pressures for 75S-T and 14S-T

Figure 30 shows the effect of upset-current magnitude on the upset-pressure requirements for 75S-T and Fig. 31 presents similar data for 14S-T. The alloy 14S-T is known to be one of the most resistant of aluminum alloys to loss of strength at elevated temperatures, and this is borne out by its behavior as a result of application of upset current. As shown in Fig. 31 for 14S-T, only a gradual reduction in the upset-pressure requirements was observed until upset currents in excess of 100,000 amp./in.² were utilized. This observation should be verified by comparison with Fig. 30 which shows similar data for the more rapidly affected 75S-T. The alloy 75S-T, although exhibiting higher strengths at low temperatures, shows a much more rapid decrease in strength with increase in temperature. In Fig. 30 this is supported by the fact that a more significant decrease in upset-pressure requirements is noted with lower upset-current magnitudes than was the case with 14S-T.

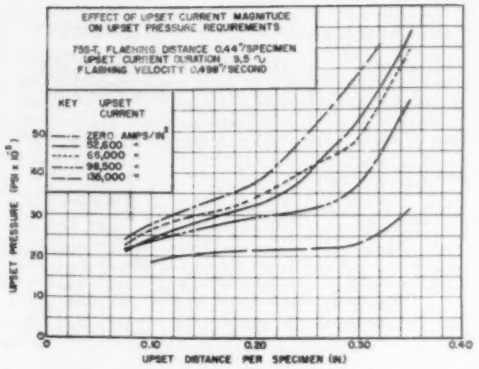

Fig. 30 Effect of upset-current magnitude on upset-pressure requirements, 75S-T

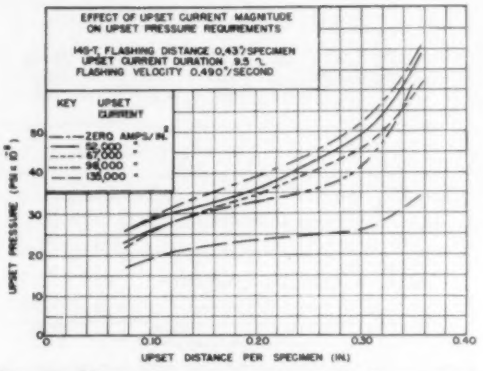

Fig. 31 Effect of upset-current magnitude on upset-pressure requirements, 14S-T

Flash Welding 24S-T

The alloy 24S-T is unusual in its behavior when flash welded. Specimens of 24S-T 0.250 x 1 in. were welded with two different flashing velocities with upset currents of from zero to 110,000 amp./in.² for 9.5 cycles. Although the upset-pressure requirements for fast flashing velocities with no upset current were too great to produce satisfactory welds, all other conditions investigated yielded welds having a tensile strength equal to the parent strength. The temperature distributions resulting from each of the two flashing velocities studied with 24S-T are shown in Figs. 32 and 33. The thermal properties of 24S-T being very similar to those of 75S-T, the temperature distribution for the medium velocity with 75S-T, shown in Fig. 24, falls between the temperature distribution curves for the slow and fast flashing velocities with 24S-T, as would be expected. The temperature distribution produced by a given flashing velocity is steeper for 24S-T than that produced in 61S-T and 14S-T, and may be considered as comparable to that produced in 75S-T.

Examination of Figs. 34 and 35 shows hardness

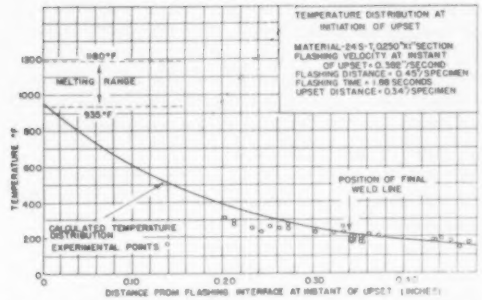

Fig. 32 Temperature distribution curves, for 24S-T, 0.250- x 1-in. section, flashing velocity—0.382 in./sec.

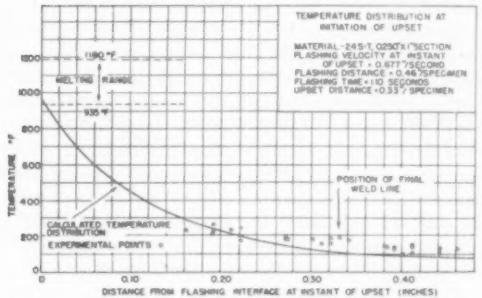

Fig. 33 Temperature distribution curves, for 24S-T, 0.250- x 1-in. section, flashing velocity—0.677 in./sec.

traverses of typical welds made in 24S-T. It will be noted that the hardness at the weld line is greater than that of the parent material even with upset currents of 110,000 amp./in.^{2} with the fast flashing velocity. There is slight evidence of overaging in the form of a slight dip in the hardness curve approximately 0.18 in. from the weld line, but the effect is minor compared with that shown by other alloys investigated.

The unusual behavior of 24S-T may be due to one or both of two phenomena. The alloy 24S-T is known to work harden readily, and, therefore, may regain some of the loss of properties due to overaging by a work hardening produced by upset. A second factor which may contribute to the retention of strength in the as-welded condition arises from the fact that 24S-T is capable of room temperature aging. This coupled with the fact that partial resolution is possible at the temperatures attained near the weld line, permits the restoration of properties upon aging at room temperature after welding.

Upset Pressures for 24S-T

Figure 36 shows th. effect of flashing velocity and upset current on the upset-pressure requirements for flash welding 24S-T. Two important conclusions are evident from this figure.

1. Reductions in the upset-force requirements are

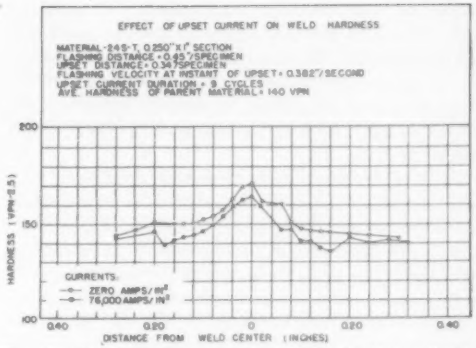
EFFECT OF UPSET CURRENT ON WELD HARDNESS
MATERIAL-24S-T, 0.250"x1" SECTION
FLASHING DISTANCE = 0.457"/SPECIMEN
UPSET DISTANCE = 0.347"/SPECIMEN
FLASHING VELOCITY AT INSTANT OF UPSET = 0.382"/SECOND
UPSET CURRENT DURATION = 9 CYCLES
AVE. HARDNESS OF PARENT MATERIAL = 140 VPN
CURRENTS:
ZERO AMPS/in.^{2}
76,000 AMPS/in.^{2}
HARDNESS (VPN-2.5)
DISTANCE FROM WELD CENTER (INCHES)

Fig. 34 Hardness traverses for 24S-T, flashing velocity 0.382 in./sec.

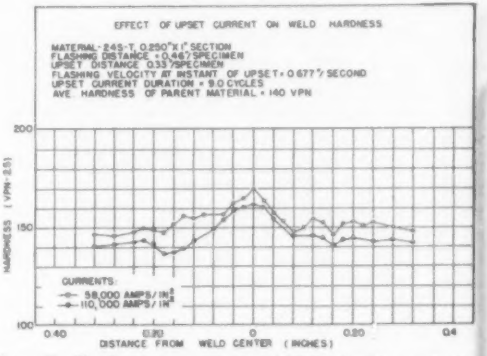
EFFECT OF UPSET CURRENT ON WELD HARDNESS
MATERIAL-24S-T, 0.250"x1" SECTION
FLASHING DISTANCE = 0.467"/SPECIMEN
UPSET DISTANCE 0.337"/SPECIMEN
FLASHING VELOCITY AT INSTANT OF UPSET = 0.677"/SECOND
UPSET CURRENT DURATION = 9.0 CYCLES
AVE. HARDNESS OF PARENT MATERIAL = 140 VPN
CURRENTS:
58,000 AMPS/in.^{2}
110,000 AMPS/in.^{2}
HARDNESS (VPN-2.5)
DISTANCE FROM WELD CENTER (INCHES)

Fig. 35 Hardness traverses for 24S-T, flashing velocity 0.677 in./sec.

more sensitive to flashing velocity with 24S-T than with the other alloys studied. Comparison of the curves for upset-pressure requirements shows that reduction of from 25 to 35% in the upset-pressure requirements for 24S-T is possible by reducing the flashing velocity from 0.677 to 0.382 in./sec. when utilizing 58,000 and 55,000 amp./in.^{2}, respectively.

2. The 24S-T alloy responds much more readily to the application of upset current for the purpose of re-

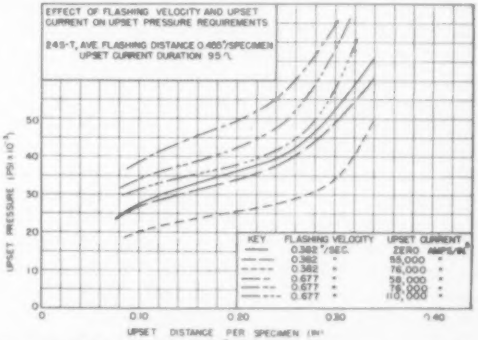
EFFECT OF FLASHING VELOCITY AND UPSET CURRENT ON UPSET PRESSURE REQUIREMENTS
24S-T, AVE. FLASHING DISTANCE 0.465"/SPECIMEN
UPSET CURRENT DURATION 9.5 C.
KEY
FLASHING VELOCITY
UPSET CURRENT
0.382"/SEC. ZERO AMPS/in.^{2}
0.382 " 55,000 "
0.382 " 76,000 "
0.677 " 58,000 "
0.677 " 76,000 "
0.677 " 110,000 "
UPSET PRESSURE (PSI x 10^3)
UPSET DISTANCE PER SPECIMEN (in.)

Fig. 36 Effect of flashing velocity and upset current on upset-pressure requirements, 24S-T

ducing the upset-pressure requirements. Comparison of the curves for the two different values of upset current 55,000 and 76,000 amp./in.^{2} shows a considerable reduction in the upset-pressure requirements for this increase in current magnitude, whereas no significant decrease was noted for a similar change with 61S-T, shown previously in Fig. 21.

The much greater rate of increase in upset force with increasing upset distance, may be taken as an indication of the greater ability for work hardening of this alloy. This rapid increase in upset-pressure requirements agrees with the evidence shown previously in Figs. 34 and 35, presented in the form of hardness survey, which indicate a sharp rise in hardness near the final weld interface.

DISCUSSION OF RESULTS

Optimum welding conditions were determined for 61S-T, 75S-T, 14S-T and 24S-T and it was found that nearly 100% tensile-joint efficiency could be obtained over a wide range of welding conditions. The practical value of upset current as a means of reducing the upset-pressure requirements was demonstrated, and a comprehensive study of upset-pressure requirements was performed. By application of the data presented on the effect of upset currents of various magnitudes upon the tensile strength and upon the upset-pressure requirements, intelligent selection of welding variables should be possible. The data on upset-pressure requirements as a function of upset distance should also prove useful in determining the capacity of existing flash welders, and in the design of new equipment for flash welding the structural-aluminum alloys. While, in general it was found that upset currents of 70,000 amp./in.^{2} or less for 9.5 cycles did not appreciably decrease the weld strength in any of the alloys, the effects of such currents in reducing the upset-pressure requirements varied with the alloy. The alloy 61S-T, the lowest strength-alloy studied, required higher upset currents in order to materially reduce the upset pressures; and some overaging, with accompanying loss of properties, was found to occur whenever an appreciable reduction in upset pressure was obtained. Since, however, this alloy is rarely used where high strengths are required, the use of upset currents greater than 70,000 amp./in.^{2} is felt to be justifiable with this alloy, in view of the fact that a 50–75% reduction in upset pressures was shown to be possible without reducing the weld strength to less than 85% of that of the parent metal. The alloys 14S-T and 75S-T showed a similar reduction in upset-pressure requirements when upset current densities of greater than 70,000 amp./in.^{2} were utilized, but neither alloy proved to be as susceptible to overaging as the 61S-T. The alloy 24S-T showed the greatest percentage reduction in upset-pressure requirements through the use of upset currents with the least loss in the properties of completed welds. The use of upset currents of up to 110,000 amp./in.^{2} was found to be possible without materially decreasing the weld strength in this alloy, and the percentage decrease in upset-pressure requirements was greater for a given upset current with this alloy than with any other alloy studied.

The results of studies made of the effect of upset currents on temperature distribution, mechanical properties and upset-pressure requirements demonstrate the following principles.

1. The degree of overaging is governed primarily by the peak temperature attained and the length of time experienced at elevated temperatures.

2. The amount of reduction in upset-pressure requirements depends primarily on the temperature distribution during upset, but also to some extent on the peak temperature.

In general, fast flashing velocities produce steep temperature gradients in the material at the end of flashing, and the faster the flashing velocity, the steeper is the temperature gradient. The existence of a steep temperature gradient at the end of flashing was found to give steep temperature gradients throughout the upset period as well, and the application of upset current was found to raise the gradient to higher temperatures over its entire length. Therefore the temperature distribution throughout the welding operation is primarily dependent on the flashing velocity, while the peak temperature experienced by the material which ultimately reaches the final weld line was found to be primarily a function of the magnitude and duration of the upset current. The time at temperature is dependent on the temperature gradient, and therefore on the flashing velocity, since heat flow away from the final weld line is faster with a steep temperature gradient.

In general, each alloy appears to have a characteristic temperature range where the compressive strength decreases rapidly with slight increase in temperature. The alloy 61S-T appears to overage quite readily in this range of temperatures, so that reduction of upset pressures through the use of upset currents is accompanied by loss of strength in the completed weld. The alloy 14S-T shows less tendency to overage in the range of temperatures where rapid decrease in tensile strength is encountered, and the alloy 75S-T still less tendency to overage. The alloy 24S-T showed the greatest percentage reduction in upset-pressure requirements by the application of upset currents, and the least reduction in weld strength for a given upset current.

The data obtained indicate that welding conditions which result in steep temperature gradients are less desirable if the aim is to reduce the upset-pressure requirements, since the important consideration in such a case is to increase the temperature of as much material as possible to a point where the compressive strength is appreciably diminished. In order to get the maximum reduction in upset pressures with the least amount of overaging, the peak temperature and the time at temperature should be as low as possible. Steep temperature gradients restrict the region in which an appreciable reduction in compressive strength is realized for a given peak temperature, and therefore are not as effective in decreasing the upset-pressure requirements.

On the other hand, the loss in strength resulting from overaging is nearly independent of the width of the overaged region, the loss being the same for a wide region of overaging as for a narrow region. The steepness of the temperature gradient, therefore, was important in this respect only as it influenced the time at temperature. In general, the steeper the temperature gradient the shorter is the time at temperature. It therefore becomes apparent that the selection of welding variables must represent a compromise between the optimum conditions for reducing the upset-pressure requirements and the conditions which reduce the tendency for overaging. The choice of suitable variables is, however, simplified by the use of the data presented in the preceding section of this report.

Throughout the course of the present investigation, an upset distance of approximately 1.5 times the section thickness was employed. Previous work[3] indicated that this amount of upset was at all times sufficient to remove any trace of oxides from the weld line. The upset pressure requirements indicate that a considerable reduction in upset pressure would be possible with less upset distance, and the data previously presented may be used to determine the amount of upset pressure required for any desired upset distance less than that used in this investigation. In selecting upset distance values for sections thicker than $^1/_4$ in., it is recommended that hardness measurements or preferably a microscopic examination be made to investigate the possibility of oxidized material at the weld line.

The hardness data included in this report, indicate that the hardness measurements may be utilized as a rapid method of evaluating the selection of welding conditions. Extensive reductions in hardness near the weld line may be taken as indicative of the presence of overaging and accompanying loss in tensile strength.

CONCLUSIONS

1. Nearly 100% tensile-joint efficiencies may be expected in welds of the aluminum alloys: 61S-T, 75S-T, 14S-T and 24S-T. These weld strengths can be obtained over a wide range of welding conditions.

2. Upset current magnitudes of 70,000 amp./in.^{2} of section for durations of up to 9 cycles, and magnitudes of 50,000 amp./in.^{2} or less for durations of up to 25 cycles are not detrimental to weld strength for 61S-T, 75S-T and 14S-T.

3. The peak temperatures measured for conditions described in conclusion 2 were approximately 600° F. The application of greater upset current results in a peak temperature greater than 600° F. and overaging results, the extent of overaging being greater the higher the peak temperatures and the longer the time at elevated temperatures.

4. Although overaging becomes evident in 61S-T, 14S-T and 75S-T when the peak temperature exceeds 600° F., the amount of overaging encountered in the three alloys for a given peak temperature differs, the order of sensitivity to overaging being greater for 61S-T, and least for 75S-T.

5. The alloy 24S-T exhibits 100% tensile-joint efficiency even with upset-current densities of 110,000 amp./in.^{2} This alloy is known to work harden readily and therefore may regain some of the loss of properties resulting from overaging by work hardening during upset. The retention of high strength in this alloy may also be due in part to resolution during the upset period and restoration of properties by aging at room temperature.

6. Upset distances of approximately 1.5 times the gage thickness appears sufficient to assure elimination of oxides at the weld interfaces in all cases.

7. The effect of upset-current density on temperature distribution and on mechanical properties of the completed weld is independent of section size within the limits investigated.

8. Greater upset distances may be obtained with smaller upset forces by utilizing upset current to raise the temperature a sufficient amount to reduce the compressive strength of the material.

9. The effect of welding variables on the upset-pressure requirements were investigated and the results were presented in graphical form.

10. The amount of reduction in upset-pressure requirements depends primarily on the temperature distribution during upset, but also to some extent on the peak temperature.

11. Steep temperature gradients, associated with fast flashing velocities, increase the upset-pressure requirements.

12. If a 10% decrease in weld strength may be tolerated, the following reduction in upset-pressure requirements may be realized through the use of upset currents: 61S-T, 40%; 14S-T, 45%; 75S-T, 65%. In the case of 24S-T, at least a 50% decrease in upset-pressure requirements is possible with no sacrifice of weld strength by the use of upset current.

ACKNOWLEDGMENTS

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The Spreading Resistance of Contacts

A study of the electrical resistance of contacts resulting from the constricting effect of the contact subareas which produces nonuniform current flow in the contact materials

by W. B. Kouwenhoven and W. T. Sackett, Jr.

INTRODUCTION

CONTACT between two metallic surfaces is never uniformly produced over the entire apparent contact area. Actual load-bearing contact occurs only at small subareas. This phenomenon gives rise to contact resistance. This resistance may be divided into two components: one, a resistance at the contact, R_c, due to absorbed gases, oxide layers or grease films at the small subareas, and two, the spreading resistance, R_s, resulting from the constricting effect of the contact subareas, which produces nonuniform current flow in the body of the contact materials.

This paper presents a study of this second component, the spreading resistance of contacts. The spreading resistance was determined for round and square rods, and flat strips in which a constriction was introduced by machining away part of the material. The influence of the size, location, shape and number of the constrictions on the spreading resistance was investigated. The work was made possible by the Resistance Welding Fellowship established at the School of Engineering, The Johns Hopkins University, by the Resistance Welding Committee of the Welding Research Council.

SPREADING RESISTANCE

The resistance of a long uniform rod is given by $R = p\,l/A$, where p is the specific resistance, l the length, and A the cross-sectional area.

When a constriction is introduced in such a rod, the current flow is no longer uniform. The current density is increased at the center and reduced at the corners. The material is no longer fully utilized as it was by uniform flow, and there is an increase in resistance, which has been termed spreading resistance.

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The spreading resistance is the only resistance that exists between two clean, film-free metal surfaces in contact. The spots where actual contact is made will be of various shapes and sizes located at random throughout the apparent contact area, and under these conditions the resistance resulting from the nonuniform current flow, i.e., the spreading resistance, will constitute the total contact resistance.

SPECIMENS

The method adopted for the study of the spreading resistance was to measure the increase in resistance produced by making lathe or saw cuts in the central section of a specimen. A typical round-rod specimen is shown in Fig. 1.

Each specimen was first checked for uniformity of dimensions and resistance and then its resistance between two knife edges 8 in. apart was measured in a Kelvin Double Bridge circuit. Then the central section was machined to the desired constriction. When this was completed, the resistance was again measured between the knife edges.

The spreading resistance, R_s, was determined from these two resistance measurements as follows: From the results of the first measurement the resistance to uniform current flow, R_A, per unit length and the specific resistance of the sample was calculated. In addition, the resistance to uniform flow, R_a, per unit length of the reduced section was determined. If R_o equals the measured resistance of the rod after the constriction was made, then

$$R_s = R_o - (R_A l_1 + R_a l_2)$$

where l_1 is the rod length of diameter d_1 and l_2 the length of the constricted portion of diameter d_2, see Fig. 1. In the above equation, R_s is the spreading resistance of the specimen due to nonuniform current flow in the rod at both ends of the constriction. In cases where current flows from a small diameter wire into the end of a larger diameter rod, there is only a single constriction in the circuit. Then the nonuniform current flow in the rod will set up a spreading resistance, R_1', which equals one half of R_s.

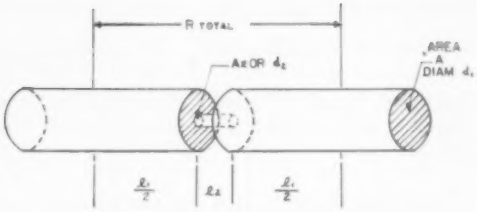


Fig. 1 Round-rod specimens

EXPERIMENTAL PROCEDURE

The measurements were made with direct current using a special Kelvin Double Bridge constructed for the purpose. During the measurements each sample was immersed in an oil bath. Standards for each different specimen tested were made from the same material in order to simplify the temperature problem. Care was taken to avoid local heating. At all times the accuracy of the measurements was better than one part in 1000. This was found to be ample as the spreading resistance is larger than one might anticipate.

CONCENTRIC CONSTRICTIONS: ROUND SPECIMENS

The spreading resistance for bronze rods having diameters of $^5/_8$ and 1 in., respectively, and concentric constrictions of different amounts are plotted in Fig. 2. In the figure the abscissa is the ratio of the diameter of the rod to the diameter of the constriction and the ordinate is the spreading resistance. A study of Fig. 2 makes it clear that for each diameter of rod, there is a separate curve when the results are plotted to these coordinates. The results, however, may be expressed in a dimensionless basis by multiplying the spreading resistance by the rod's diameter, d_1, and dividing by the specific resistance, p. Thus when the ordinate of the curve is $R_s d_1/p$, it will be found that all of the points lie on the same curve irrespective of diameter and material.

The results found for concentric constrictions on aluminum, bronze, copper, copper-nickel, iron and nickel rods ranging in diameter from 0.45 to 1 in. and with varying size constrictions are plotted in Fig. 3. These points, when plotted on this dimensionless basis, all lie on a smooth curve that checks closely with the solution of the Laplace equation for this boundary value problem as given by Dr. L. C. Roess:[1]

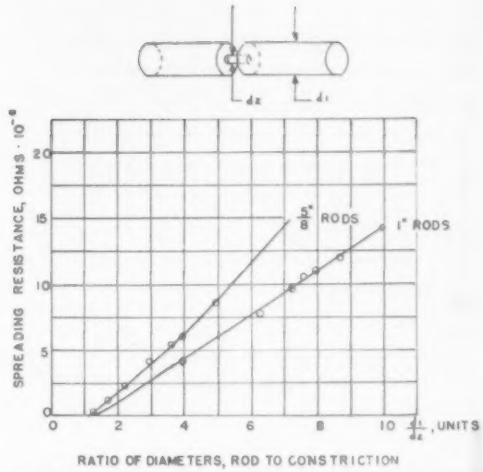


Fig. 2 Spreading resistance for rods with constrictions

$$\frac{R_s d_1}{p} = \frac{d_1}{d_2}\left[1 - 1.409\left(\frac{d_2}{d_1}\right) + 0.296\left(\frac{d_2}{d_1}\right)^3 + 0.052\left(\frac{d_2}{d_1}\right)^5 + \ldots\right]$$

This solution has been plotted for a larger scale of ratios, d_1/d_2, in Fig. 4. The points for magnetic materials fit the curve as well as the other materials. In these studies, a leaded commercial bronze was found to be the best material for ease of machining and homogeneity, hence was used most in later studies.

In the mathematical solution of this problem, certain

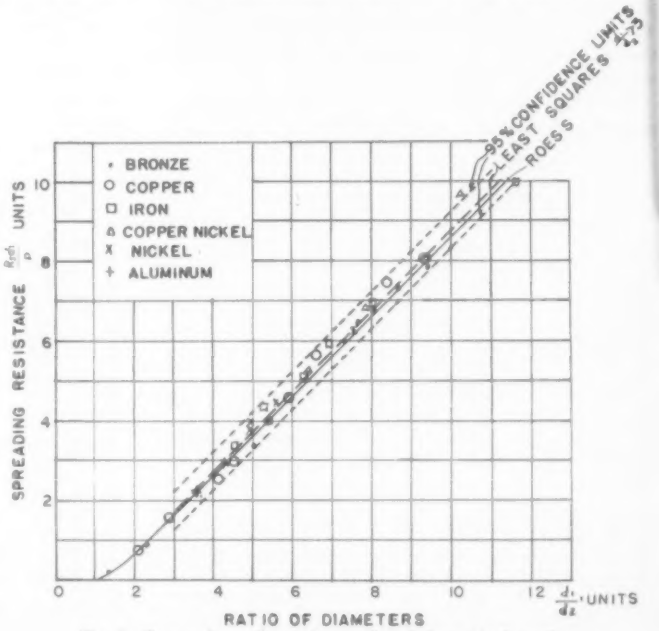


Fig. 3 Comparison of experimental and theoretical results

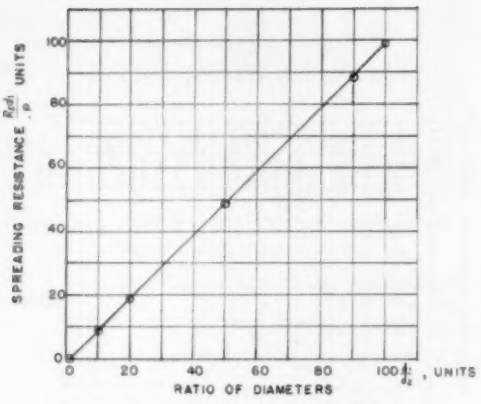


Fig. 4 Spreading resistance for round rods

assumptions were necessary. The validity of these assumptions is confirmed by the experimental measured values. A statistical analysis of the results shows that the least squares line closely coincides with the linear portion of theoretical curve, and that the 95% confidence limits embrace a narrow band. These are also plotted in Fig. 3.

SYMMETRIC CONSTRICTIONS: FLAT STRIPS

The spreading resistance was measured on a number of flat strips of brass with a constriction located at the midpoint of the strip. A typical specimen is shown in Fig. 5. The results of these measurements are also plotted in Fig. 5, where the abscissa is the ratio of the width of the strip to the width of the constriction, and the ordinate is on a dimensionless basis, $R_s w/\rho$. Here w is the thickness of the strip.

The solid curve is based on an analytical solution given by Smythe,[2] which can be written:

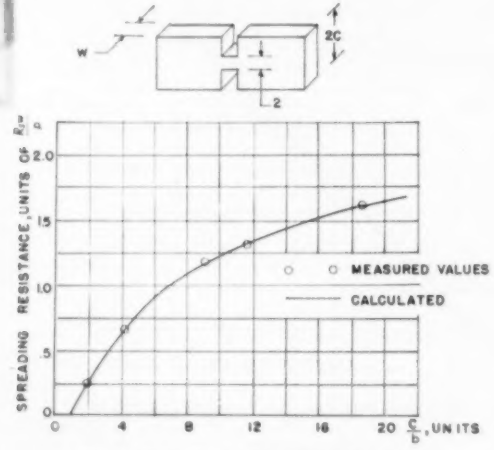


Fig. 5 Spreading resistance for flat strips

$$\frac{R_s w}{\rho} = \frac{l}{\pi}\left[\frac{(x+1)^2}{x}\ln(x+1) - \frac{(x-1)^2}{x}\ln(x-1) - 2\ln 4x\right]$$

Here x is the ratio of the width of the strip to the width of the constriction. The experimental points check this solution.

SQUARE BARS WITH SYMMETRICAL SQUARE CONSTRICTIONS

A number of brass bars of square cross section, having symmetrically located square constrictions (see Fig. 6) were measured, with the results shown by the coded points plotted on the same figure. The abscissa, W_1/W_2, is the ratio of the width of the bar to the width of the constriction. The dimensionless quantity, here found to be independent of the size of the material, $R_s W_1/\rho$, is the ordinate. The experimental points are for two different size bars, $^1/_2$ and 1 in.; the points for both sizes fit the same curve.

One would intuitively expect that a bar of a given cross-sectional area, with a constriction of a given cross-sectional area, would have approximately the same spreading resistance whether the bar and constriction were round or square in shape. Indeed, one might well expect the square shape to give a slightly higher resistance because of the sharp corners. Yet, when the Roess curve for circular bars is plotted directly to the coordinates of Fig. 6 (Curve 2), it lies above the experimentally determined points. It is necessary to examine the dimensionless quantities in the two cases. For square bars the quantity is $R_s W_1/\rho$, for circular rods, $R_s d_1/\rho$, where W_1 is the width of the bar and d_1 is the diameter of the rod. For bars of equal cross section W_1 is less than d_1 by the factor $\sqrt{\pi}/4$. When the ordinates of Curve 2 are multiplied by this factor, it coincides with Curve 1. The experimental data fits this curve quite well with the points falling a little high as expected.

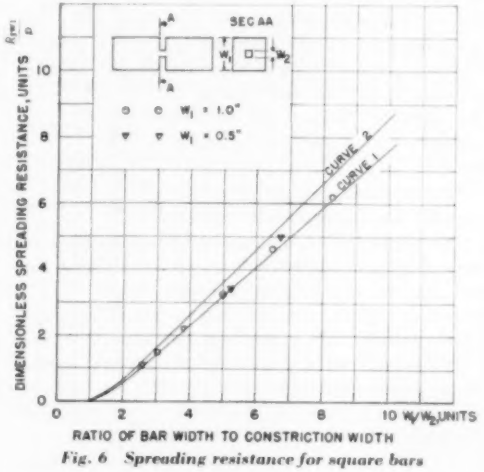


Fig. 6 Spreading resistance for square bars

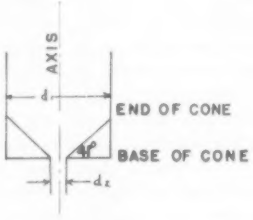
EQUIVALENT ANGLE OF UNIFORM FLOW

In a previous paper[3] it was shown that the spreading resistance of round rods could be computed with fair accuracy by assuming that the current was constrained to flow in a truncated cone whose sides made an angle of 41° with the contact surface. It was also shown that for flat strips, an angle of flow from the contact surface of 41.3° gave a reasonably good fit with experimental data. It is interesting to note that a similar calculation for square bars requires an angle of 44.5° to fit the experimental data.

While this concept may help one to visualize the order of magnitude of the spreading effect, it is artificial and could be misleading.

DISTRIBUTION OF SPREADING RESISTANCE

Using the concept of an equivalent cone of current flow, a qualitative picture of the distribution of the spreading resistance along the axis of the rod was obtained starting from the base of the cone and extending to the point where the cone ended at the surface of the rod. This distance was divided into ten equal parts and the distribution of the spreading resistance for a single constriction, R_s', determined for three ratios of d_1/d_2, namely, 5, 11 and 101.



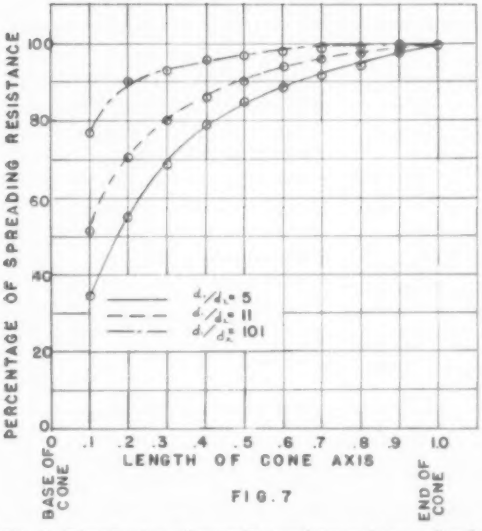


Fig. 7 Distribution of spreading resistance in round rods

The results are plotted in Fig. 7. This figure shows clearly that the major portion of the spreading resistance is located close to the constriction, and that the percentage so located increases as the ratio of d_1/d_2 becomes larger.

LENGTH OF CONSTRICTION

In practice the length of the constricted path is usually quite small. The question therefore arose: does the length of the constricted path have any effect upon the spreading resistance? Measurements were made on round specimens in which the length of the constricted path was varied from 0.163 to 0.007 in. Within experimental limits the spreading resistance was found to be independent of the length of the constriction, and the points fell on the smooth curve of Fig. 3. This indicates that any nonuniform flow in the constricted portion contributes a negligible spreading resistance compared to the spreading resistance of the large diameter sections.

LOCATION OF THE CONSTRICTION

On actual contacts the constricting area is not symmetrically located, but may be at any point on the surface. The effect on the spreading resistance produced by nonsymmetrically or eccentrically located constrictions was studied for both flat and round specimens. Specimens were made in which the constriction was held to a fixed size and on successive specimens its location was varied from the center to the extreme edge. The results are plotted in Fig. 8 for a ratio of $d_1/d_2 = 8.5$ for the round specimens and for ratios of $c/b = 12.5$ and 25 for the flat samples. The curves for the two types of specimens are similar in shape.

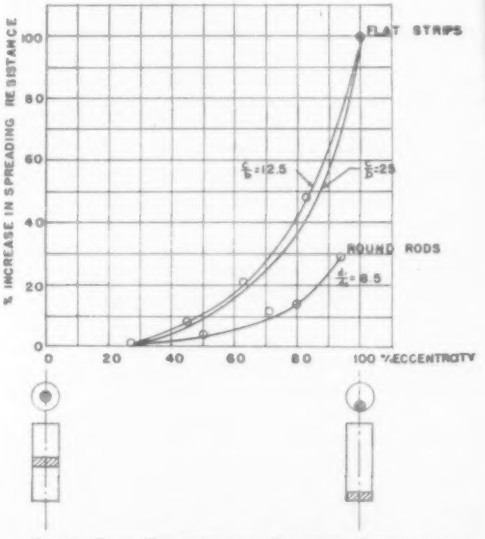


Fig. 8 Spreading resistance for eccentric contacts

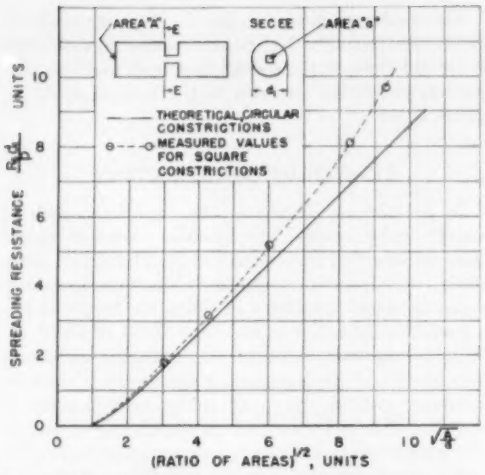


Fig. 9 Spreading resistance of round rods, with square constrictions

A study of Fig. 8 shows that the location of the contact spot does not have much effect on the spreading resistance until the eccentricity exceeds 50% for strip specimens and 60% for round ones. The effect is naturally greater for flat strips because in these the flow lines are more severely restricted than in the round specimens. It was also found that as the area of the constriction was reduced, the effect of nonsymmetrical location was slightly less marked as may also be seen from the figure.

SHAPE OF THE CONTACT AREA

The studies described above on the spreading resistance of different types and sizes of rods, were all characterized by the similarity between the constricting area and the full-sized rod. Such similarity in practical contacts would be highly improbable. Where contact occurs by virtue of metal being squeezed into fissures made in surface films by high contact pressures, the contacting areas would tend to be elliptical rather than circular or square. An experimental study of the influence of the shape of the constriction was therefore made. Since it would have been extremely difficult to construct samples with elliptical constrictions, the following approach was used.

The spreading resistance of round rods having square symmetrical constrictions was determined for different constricting areas. A comparison of these measurements with the results for circular constrictions is shown in Fig. 9. The dimensionless quantity $R_s d_1/\rho$ is plotted as ordinate against $\sqrt{A/a}$ as abscissa. A is the cross-sectional area of the round rod, and a that of the constriction. The solid curve gives the results for round constrictions, while the circled points and dotted curve are measured values found for square constrictions. Again the effect of the square corners is to increase the spreading resistance.

The next step in the exploration of the shape effect was to test a series of samples having rectangular constrictions with the same total area, mn being held constant. It was then possible to determine the relation of spreading resistance to a shape factor, here defined as the ratio of the length, m, to the width, n, of the rectangular constriction, see Fig. 10.

Holm has shown[4] that the effect of the shape of the constriction can be calculated if one assumes the constricting area to be an ellipse of area much smaller than the cross-sectional area of the rod. Then if R_{mn} is the spreading resistance for an elliptical constriction with major axis, m, and minor axis, n, and if R_{dd} is the spreading resistance of a circular constriction of diameter d

$$\frac{R_{mn}}{R_{dd}} = \frac{K(k_1)}{\pi}\left(\frac{4d}{m+n}\right), \text{ where } k_1 = \frac{m-n}{m+n}$$

k_1 is the modulus of K, a complete elliptical integral of the first kind.

The dotted curve of Fig. 10 is a plot of the above equation. Also in Fig. 10 are the experimental curves for two series of samples with rectangular constrictions, one of area 0.015 sq. in. and one of 0.038 sq. in. All three curves coincide for an m/n less than three, where the constriction is well centered. The curve for the smaller area more nearly fits that of Holm's formula, and this is quite reasonable, since Holm assumed a very small constricting area. It is perhaps worth comment that for a given total constricting area, a long thin constriction gives appreciably less spreading resistance than a round constriction, but the magnitude of the decrease would be less than 25% for reasonable shapes.

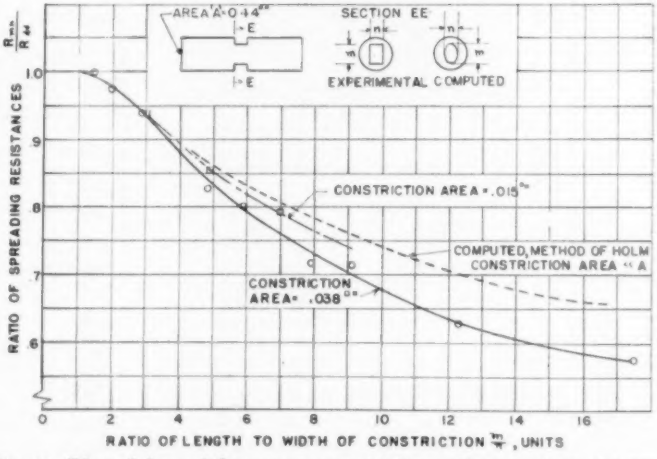

AREA "A" = 0.14"
SECTION EE
EXPERIMENTAL COMPUTED
CONSTRICTION AREA = .015"
COMPUTED, METHOD OF HOLM CONSTRICTION AREA "A"
CONSTRICTION AREA = .038"
RATIO OF SPREADING RESISTANCES $\frac{R_{mn}}{R_{dd}}$
RATIO OF LENGTH TO WIDTH OF CONSTRICTION $\frac{m}{n}$, UNITS

Fig. 10 Effect of shape of the contact or constriction on the spreading resistance

PARALLEL CONSTRICTIONS

Study of the contribution of spreading resistance to contact resistance should involve an inquiry concerning the effect of two or more constricting paths in parallel across the contact surface. When force is applied to the contact members, the yield point of the first contacting areas is quickly reached and flow occurs until enough of the apparent contact area is in load-bearing contact to reduce the pressure below the plastic flow limit of the metal. During this process the number of conducting constrictions that form will depend on the surface shape and finish. Holm[5] states that the total load-bearing contact area S_b will be relatively constant for a given contact load (P) and contact material, and is of the order of magnitude $S_b = 2P/H$, where H is the upper limit of the contact pressure at which plastic flow or splintering occurs.

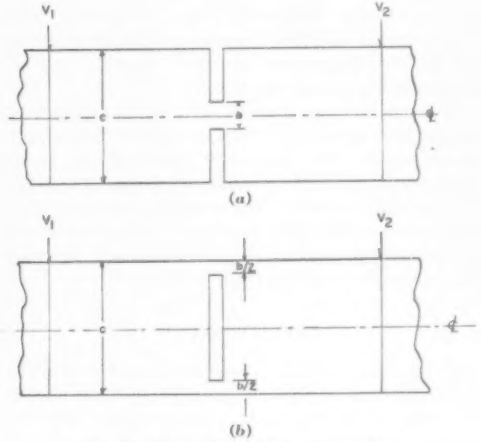


Fig. 11 Brass strips with constrictions

Windred[6] has stated, "When there is more than one contact point, there may be electromagnetic interactions between the lines of current flow if the contact points are close together, otherwise this may be neglected." Holm[7] uses the phrase "the constricted lines of flow influence each other" if the conducting spots are close together. Both state that if the spots are far apart, the total spreading conductance can be computed by adding the conductances of the individual spots.

The concept of the flow lines of parallel constrictions influencing each other is misleading and that of self or mutual electromagnetic forces on the flow lines under steady flow conditions is probably erroneous. To check this the following experiment was devised. Consider the brass strip with a constriction (two dimensional flow) as shown in Fig. 11 (*a*). The flow is symmetrical about the center line; hence, the total resistance of the strip between knife edges V_1 and V_2 should be exactly half that of the individual halves of the strip. Further, if the strip is separated at the center line and put together as in Fig. 11, exactly the same resistance should be obtained between the knife edges barring disturbance of the flow by electromagnetic forces.

The experiment was performed on several brass strip samples, and each time the spreading resistance of a sample constructed as shown in Figure 11 (*b*) was found to be equal to the corresponding sample Fig. 11 (*a*), within the experimental limits. Hence, one can conclude that mutual electromagnetic forces of parallel flow have no practical effect on spreading resistance.

This does not mean, however, that the spreading resistance of parallel constrictions is independent of the spacing between them. It was found that the spreading resistance for single constrictions changes with their location as shown in Fig. 8. The influence of the spacing of parallel constrictions on the spreading resistance was studied on 13 brass strip samples. Each strip was 1.5 in. wide and $^1/_8$ in. thick and each had two symmetrically located parallel constrictions of 0.062 in. wide. All factors were held constant except that the spacing was varied from zero to the maximum possible value. The data is plotted in Fig. 12 where the abscissa is the spacing between the constrictions, the ordinate, the dimensionless spreading resistance R_sW/ρ. The solid curve of Fig. 12 was computed from the data of Figs. 5 and 8 by considering the single strip as consisting of the parallel connection of two separate strips half as wide with eccentrically located constrictions. The circled points are the measured values for the thirteen specimens.

It was found that the spreading resistance for two parallel constrictions separated by half the strip width,

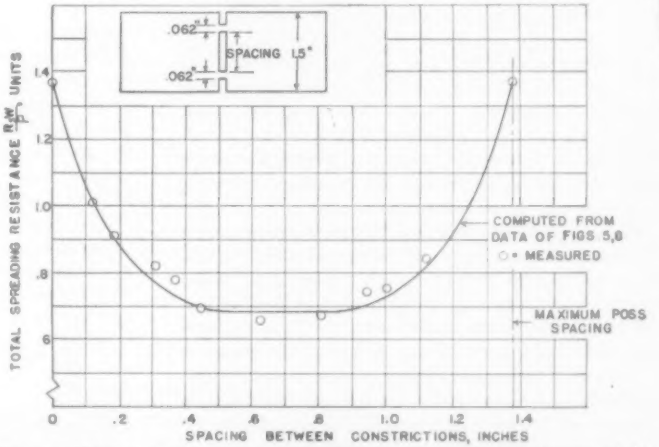


Fig. 12 Effect of spacing of two constrictions on spreading resistance of flat strips

was exactly half that obtained when the spacing was zero (single constriction 0.124 in. wide.)

CONTROL OF SPREADING RESISTANCE—MULTIPLE CONTACT POINTS

Assuming that Holm is correct in his statement that the total contact area is dependent mainly on the load and the materials in contact,[5] it follows that the total contact area may be concentrated in a single spot or may be distributed randomly in small subareas over the surface. What effect does this have on the resulting spreading resistance and how may this resistance be controlled? The experimental work indicates that the spreading resistance of two metals in contact may be controlled by varying the number of contact points. For any given total contact area the lowest spreading resistance will be obtained with the maximum number of symmetrically located constrictions or contact subareas. As the number of contact points is increased, while keeping the total contact area constant, the resulting spreading resistance approaches zero, even though the area of the individual constriction or contact points also approaches zero. Verification of this statement is based on the following analysis.

It can be seen from Smythe's[2] analytical solution that the value of the spreading resistance in ohms for a flat strip specimen with a symmetrical constriction varies only with the ratio of the width of the strip to the width of the constriction.

Assume that we have a strip of width c and thickness w with a symmetrical constriction of width b and a thickness w. This strip will have a spreading resistance of R_s ohms. Assume now that this strip is replaced by two strips each of width $c/2$ and each with a symmetrical constriction of width $b/2$, both strips having the thickness w. Now each half strip will have a spreading resistance R_s, identical to that of the full-sized strip.

If these two strips are joined in parallel, their individual spreading resistance R_s will also be in parallel and the resultant spreading resistance will be $R_s/2$. This is confirmed by the experimental results, Fig. 12.

Assume now that each half strip is divided into two strips of width $c/4$ and each with a symmetrical constriction of width $b/4$. Each one of these four strips will have a spreading resistance of R_s equal to that of the original full-sized specimen. When these four strips are joined in parallel the resulting spreading resistance will be one-fourth of R_s.

The analysis indicates that the resulting spreading resistance of a specimen with a large number of paths in parallel approaches zero as the number is increased indefinitely, provided the total constricting area remains constant. If n is the number of parallel paths, symmetrically spaced, and equal in area, the spreading resistance of such a flat strip specimen becomes R_s/n, where R_s is the spreading resistance of a sample with the same total constricting area, all located in the center.

A similar analysis can be developed for round- or square-rod specimens. The analysis for a square bar is based on the dimensionless measure of spreading resistance, R_sW/p, which was shown in Fig. 6 to be dependent only on the ratio of the width of the strip to the width of the constriction.

Assume a square bar of W inches on a side and of cross-sectional area A_1, having a symmetrical constriction at the center of A_2 sq. in. This bar will have a spreading resistance $R_{s1} = Rp/W$, where R is the dimensionless spreading resistance, Fig. 6.

Now assume that this square bar is divided into quarters each of $W/2$ in. on a side, each of cross-sectional area $A_1/4$, and each having a symmetrical constriction of area $A_2/4$. Each one of these quarters will have a spreading resistance of $R_{s2} = 2Rp/W$, or twice that of the original bar. When these four quarters are joined in parallel, the resulting spreading resistance will be one-half that of the original bar with its single symmetrical constriction. In this process of subdivision, the spreading resistance decreases with the number n of conducting paths as $R_s/\sqrt{n}$. The subdividing process may be continued indefinitely so long as the dimensions are such that the flow is governed by Laplace's equation.

This analysis shows that the spreading resistance can be controlled by using the proper surface finish of the contact areas. The maximum spreading resistance will be obtained if there is a single small area of contact as in a projection weld. The spreading resistance may be reduced to a minimum by using a surface finish that provides a large number of contact points or constrictions scattered throughout the area.

APPLICATION

Assume that it is desired to spot-weld a piece of sheet steel to the end of a soft steel rod. We will investigate the value of the spreading resistance that may be attained in the rod. Assume that the rod is 1 in. in diameter, several inches in length, and that its specific resistance, p, is 8.4 microhms per inch.

In order to control the spreading resistance it will be necessary to prepare the surface of the sheet so that initially contact is made over a definite area. This might be accomplished by raising a slight projection on the sheet. Assume that the diameter of this initial contact area is one-tenth of an inch and that the surfaces of the rod and sheet are clean and in perfect contact over this small diameter. In addition, assume that this contact area is centrally located.

The curve, Fig. 4, gives the value of R_sd_1/p for the ratios of d_1/d_2; where d_1 is the diameter of the rod and d_2 the diameter of the contact area. For any desired ratio the value of R_sd_1/p may either be obtained from the curve or for ratios of five or greater it may be calculated from the formula:

$$\frac{R_sd_1}{p} = \frac{d_1}{d_2} - 1.409$$

For the assumed ratio of ten the value of $R_sd_1/p = 8.59$.

Solving this expression we obtain the total spreading resistance:

$$R_s = 8.59 \times \frac{\rho}{d_1} = 8.59 \times \frac{8.4 \times 10^{-8}}{1} =$$

$$72.2 \times 10^{-6} \text{ ohms}$$

This total spreading resistance applies to the two ends of a continuous rod with a constriction between. For the case under discussion the value of the spreading resistance in the rod alone will be one-half of R_s or 36.1 microhms.

An approximate value of the spreading resistance on the sheet may be obtained from the expression, $R_s = \rho/2d_2$, which is accurate if the sheet thickness is large compared to d_2. Substituting $R_s = 8.4/2 \times 0.1 = 42$ microhms.

The value of the spreading resistance would have been increased if the area in contact had been smaller. For example, for a contact area 1/100 of an inch in diameter the value of the spreading resistance in the rod would be 415 microhms. Smaller initial contact areas will result in still higher resistances.

The spreading resistance may also be increased by making the location of the contact area eccentric, see Fig. 8. If the initial contact area is moved to the extreme edge of the rod the maximum possible increase in resistance is 100%. This double value, however, cannot be realized in practice; for round rods the increase will amount to only 30 or 40%.

The spreading resistance in the rod may be decreased by increasing the contact area between the sheet and the rod as has already been discussed. If for mechanical reasons it is desirable to use a fixed initial-contact area, then there are two other methods by which the resistance may be reduced. One of these is to use a long narrow projection and the other is to divide the contact area into a number of small subareas in parallel.

If the projection in the sheet is made in the shape of a long narrow ridge of the same total area, the spreading resistance will be reduced. For example, if the ratio of the length of the width of the projection is twelve, the spreading resistance will be reduced to approximately 70% of its initial value as shown by Fig. 10.

If the contact area is divided by scoring the sheet into many small subareas, the spreading resistance again will be decreased. For example, if contact occurs at 100 uniformly distributed points, whose total area equals a section 0.1 of an inch in diameter, the value of the spreading resistance will be reduced by the square root of the number of contacts; that is, by a factor of ten. In that case the spreading resistance, which for a single contact area had a value of 36.2 microhms, will be 3.62 microhms. If the surfaces could be so prepared that there was uniform perfect contact over the entire area between the end of the rod and the sheet, the spreading resistance would be zero.

PROBLEMS RELATED TO RESISTANCE WELDING

A typical resistance welding setup would contain two relatively thin sheets compressed between circular electrodes. There will be three contact surfaces, one between the sheets, and one between each electrode and sheet. At each surface contact will first occur only at a few small subareas. If one assumes only one conducting subarea at each surface, the current will be constrained to flow from a tiny spot located somewhere under the upper electrode to another spot somewhere on the interface between sheets, thence to the spot on the lower electrode. It would be coincidental were these spots aligned.

A simplification of this problem was studied experimentally by using large diameter rods with two symmetrically located constrictions "in series" separated by a section of the large diameter rod of length, t, see Fig. 13.

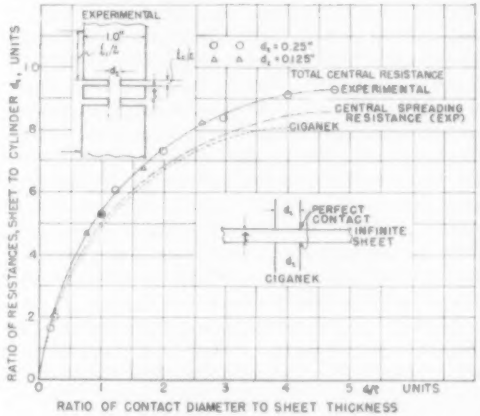


Fig. 13 Spreading resistance in thin sheets

All of these specimens had outside diameters d_1 of 1 in. The thickness, t, of the central "sheet" between the two constrictions was varied, while the diameter of the constrictions, d_2, was held constant. Two series of samples were studied, one with $d_1/d_2 = 4$, thus simulating a sheet between two perfectly contacting circular electrodes 1/4 in. in diameter; the other $d_1/d_2 = 8$. The measured total resistance, R_t, of such a sample between two knife edges a distance of $l_1 + l_2 + t$ in. apart will be:

$$R_t = R_A l_1 + R_a l_2 + R_s + R_m$$

Where R_A and R_a are the resistance per unit length of areas A and a, respectively, R_s is the spreading resistance of the two ends of the rod and is determined from Fig. 4 for the given diameter ratio. R_m is the resistance of the central or sheet section. R_m may be considered as made up of two parts: $R_{A'}$ for the thickness t of area A and R_f, an additional resistance, which exists because the current does not flow uniformly through the sheet but instead follows a fusiform path: $R_f = R_m - R_{A'}$.

In presenting the data, this central (or middle) resistance, R_m, is compared to the resistance which would be obtained if the current were constrained to flow in a right cylinder of diameter, d_2, directly through the sheet. Thus in a very thin sheet, the current would tend to

flow directly across between the two electrodes, so the central resistance would be very nearly that of the cylinder resistance, while in a thick sheet, the current would tend to spread out considerably from the imaginary cylinder boundaries; consequently, the central resistance would be considerably less than the resistance of such a cylinder connecting the two constrictions. The ordinate of Fig. 13, then, is the ratio of the resistance R_m of the central sheet to the resistance of a cylinder of diameter d_2 and length t; while the abscissa is the ratio d_2/t. The solid curve is drawn through the experimental data for the total measured central resistance R_m between the two circular contacts. The dashed curve is obtained by subtracting the uniform flow resistance, $R_A t$ from the total central resistance to obtain the central spreading resistance, R_f. This curve compares well with the dotted one of Ciganek,[8] who studied the same problem using graphical flux plotting methods for the case of an infinite sheet. His model is also shown in Fig. 13. Here the only resistance between the two perfectly contacting electrodes is a resistance R_f for the resistance of the infinite sheet to uniform flow is zero.

Use of this data may be illustrated by the following example. Assume that it is desired to develop a given amount of I^2R in a sheet of low carbon steel $^1/_{16}$ in. thick clamped between two electrodes. Three areas of electrode contact will be considered and the resistance in the sheet calculated for each.

Assume that the electrode tips are finished so that they make perfect contact over an area $^1/_4$ in. in diameter. Then $d_2/t = 4$ and R_m/R_{cyl} is found to be equal to 0.84 from Fig. 13. The resistance $R_s = \frac{\rho_s t}{a} = \rho_s \frac{^1/_{16}}{\frac{\pi}{4}(^1/_4)^2} = \frac{4}{\pi}\rho_s$. ρ_s = specific resistance of the sheet.

Therefore:

$$R_m = 8.04 \times \frac{4}{\pi}\rho_s = 1.07\ \rho_s \text{ ohms}$$

If the electrode tips are shaped to form contacts $^1/_8$ in. in diameter, the ratio of $d_2/t = 2$ and $R_m/R_{cyl} = 0.61$ (Fig. 13).
Then:

$$R_m = 0.61 \times \frac{^1/_{16}}{\pi/4(^1/_8)^2}\rho = 3.1\ \rho_s \text{ ohms}$$

If the contact area is made $^1/_{16}$ in. in diameter, then $R_m = 9.2\ \rho_s$ ohms.

Thus it is clear that for a given current and a material of known thickness and specific resistance, it is possible by choosing the proper diameter of contact to develop the desired initial I^2R loss in the material.

CONCLUSIONS

The results of this study provide an explanation of spreading resistance, and curves are presented for calculating its magnitude for single and multiple constricting contacts. The study shows that:

1. The spreading resistance forms an important part of the resistance of contacts.
2. The theoretical analysis given by Roess for symmetrical constrictions is confirmed experimentally.
3. The spreading resistance for single constrictions can reach quite high values. Indeed, the spreading resistance approaches infinity as the constricting area approaches zero.
4. Studies on the effect of the shape and location of the conducting area at the contact interface show that these have little influence on the spreading resistance until extremes of eccentricity or ellipticity are reached.
5. An analysis of multiple conducting paths in parallel across the contact interface was made possible by the dimensionless measures of spreading resistance. This analysis showed the rather remarkable possibility of there being negligible spreading resistance even for a very small total constricting area, provided the conducting area was divided into many separate paths in parallel across the interface.

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Energy Distribution in Electric Welding

Discussion by Merrill Skolnik

The authors' investigation of the submerged-melt process is interesting and contributes to the understanding of the phenomena occurring in the welding arc. There are two items upon which comment may be made. The first concerns itself with the calculation of the anode and cathode potential drops of the arc. This calculation is made by experimentally finding (1) the

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The paper by C. E. Jackson and A. E. Shrubsall was published in the May 1950 Research Suppl., page 231-s.

sum of the anode and cathode potential drops and (2) the ratio of the melting rates of the electrode with reversed and with straight polarity. The anode potential drop and the cathode potential drop are then found from this data by assuming that the ratio of the melting rates is approximately equal to the ratio of the anode and cathode potential drops. This assumes that almost all of the electrical energy available from the electrode potential drops is used to melt the electrodes. In making this assumption, account does not seem to be taken of the fact that an appreciable amount of energy available at the cathode from the cathode potential drop is used to liberate electrons from the metal. The amount of energy that is required is known as the work function of the metal, and for iron its value is about 4.8 electron-volts for each electron liberated. Exactly what portion of the available energy at the cathode is used to liberate electrons depends on the fraction of the current that is carried by the electrons. If almost 100% of the current is carried by electrons at the cathode, then the cathode drop as calculated by the authors is too low by approximately 4.8 v.

At the anode a different situation prevails. The electrons on striking and entering the anode give up energy of condensation in the form of heat. This additional heat, along with the heat produced by the acceleration of electrons through the anode drop, is used to melt the anode. Since the current at the anode is carried almost entirely by electrons, the amount of additional energy to melt the anode is given by the product of the current times the work function. In the example given in the paper the value of the anode drop is probably too high by approximately 4.8 v. Thus, at the cathode the liberation of electrons has a cooling effect while at the anode the impinging of the electrons has a heating effect; and in calculating the anode and cathode drops this must be taken into account. This is one of the reasons why the anode is usually hotter than the cathode in the electric arc. Of course there are other factors which should be considered in this determination such as heat losses and gains by conduction and radiation, I^2R losses, chemical effects and others, but these can usually be neglected in rough calculations as is done here. For precise calculations, a complete energy balance should be made at both electrodes and the value of the electrode drops may then be determined.

The other item concerns the curve of Fig. 7 which is shown extending to zero. This means that for low currents the sum of the anode and cathode drops would decrease with decreasing current and tend toward zero. The mass of data on low-current arcs in the literature shows that for low currents this sum increases rather than decreases with decreasing current. Therefore, the curve of Fig. 7 should not go to zero for decreasing current, but it should reach a minimum and then begin to rise.

Authors' Reply

The discussion by Mr. Skolnik is appreciated, particularly in view of the fine work which has been reported in related fields by the Hopkins group. We heartily agree that a complete energy balance is needed with precise measurements and exact calculations in order to definitely account for the distribution of what we have labeled auxiliary energy. However, at the present time, methods of analysis and measurement have not been developed sufficiently to provide great accuracy in this field. From a general thermodynamic approach such related factors, as ionization potential, work function, heat of reaction and free energy of ionization of the welding composition, influence melting rates. Unquestionably, the presence of a Unionmelt consisting mainly of complex silicates modifies the operation in the welding zone from that ordinarily encountered in gaseous envelopes.

At the present time, no experimental procedure has been reported for measuring the relative portions of the welding current carried by electronic and ionic conduction in the welding zone. The presence of certain oxide components in a Unionmelt will upset this relationship. The work function of something over 4 electron volts given for pure iron will be lowered considerably by the presence of oxides of elements such as sodium or calcium which in turn, would result in little modification of the anode and cathode potentials. It is to be regretted that probe measurements of other experimental techniques are not more readily applicable to study the welding zone.

A number of experimental results have pointed to the fact that the presence of Unionmelt with the accompanying high temperatures modifies our usual conception of arc phenomena. Further substantiation of the statement that the action in the welding zone is not strictly comparable to that encountered in low current arcs is the fact that the anode-cathode intercept shown in Fig. 7 continues to decrease as the current is decreased. Tests at 100-amp. welding current give an intercept of approximately 6 v. Although information for lower currents using the Unionmelt process is not available, there is no indication from the present data of a rise in the anode-cathode drop for lower welding currents.

New Procedures for Studying Electrode Coverings

A new procedure for following the variations in moisture contents with time. Identification and analysis of electrode coverings by X-ray spectrometer and optical spectrographic methods

by Jay Bland and Solomon Goldspiel

INTRODUCTION

AN EXTENSIVE program for the qualification of currently available medium steel welding electrodes is under way at the Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y. These electrodes are evaluated for compliance with the requirements of the Navy Department Specification for medium steel electrodes,[1] and represent most of the types included as the E60 Series in the A.W.S. tentative specification for mild steel electrodes.[2]

The Bureau of Ships, Navy Department, has recognized the necessity for research and development work which relates to problems arising during the evaluation of the various electrodes. With the authority and approval of the Bureau of Ships, the Material Laboratory has attempted to obtain solutions to these problems. Some of the results have been incorporated in revisions of the governing specification, and some, of general information, have been published.[3–5] In most instances, the conclusions drawn or procedures developed from the investigations have had immediate and practical applications to the evaluation program. Wherever possible, test materials and data have been those employed in and derived from the evaluation phases of the over-all program.

Two of the most perplexing problems encountered in the course of evaluations of welding electrodes are the changes in weldability characteristics that occur in a given batch over a period of time, and the variations encountered between different batches of the same brand. These changes may possibly be attributed to variations in the moisture content of the electrode coverings or actual modification of the covering constitutents or both. In view of the above, one phase of the investigation was directed toward developing methods for the determination of the quantities of moisture in electrode coverings and its effects on the weldability characteristics of the electrode as well as on the properties of the resulting weld deposit. A second phase was devoted to the development of a rapid and comparatively inexpensive method of identification and analysis of electrode coverings which would have significance in respect to weldability characteristics.

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The opinions or assertations contained herein are those of the authors and are not to be construed as reflecting the views of the Department of the Navy or of the Naval Service at large.

DEVELOPMENT OF A METHOD FOR DETERMINATION OF MOISTURE CONTENT

The medium steel electrodes received for qualification tests have coverings which contain moisture in the range of about 2.5 to 7.5% by weight. This moisture exists both as free water and as combined water of crystallization. In the latter form, the quantity of moisture in the covering depends primarily on its final processing temperature, and to a minor extent on atmospheric humidity variations; this moisture content probably has become stabilized prior to receipt of samples for testing. The amount of free water in the covering likewise depends on processing conditions; however, the quantity of this moisture is variable with changes in atmospheric humidity.

Electrode manufacturers attempt to process their particular brands to a relatively narrow range of moisture content. Extremes beyond this range are known to affect the weldability characteristics of an electrode or the physical properties of its weld deposit. Therefore it is important that any evaluation be conducted with electrodes representative of the manufacturer's production, and not with electrodes which have seriously been altered in moisture content as a result of humidity variations during storage prior to testing.

The most common methods of determining moisture content of electrode coverings involve the use of an electrical meter or the direct heating of a pulverized sample of the covering. The former method usually requires a fairly extensive calibration procedure for each particular electrode composition and covering thickness, and is used primarily for production control. It is not practicable for determinations which are conducted on a multitude of electrode brands and sizes. Direct heating of pulverized covering flakes is used generally for moisture determinations; however, this method is comparatively slow and time consuming and consequently is not practicable where individual rapid and economical determinations are required.

It was considered desirable, therefore, to develop a method for the numerous determinations of moisture content required to adequately follow variations in electrode coverings over extended periods. A procedure, taking into account the above considerations was developed.

The first step in the procedure is the determination of the moisture content of the electrodes of a given batch by direct heating of the whole electrodes or by heating of flakes of their coverings. With direct heating, moisture content is calculated from the weight loss observed and the average weight of covering for the particular electrode. Sample electrodes from the batch are then carefully weighed, identified and returned to their respective containers. In cases where samples are selected from a sealed box, the box is carefully resealed. At any subsequent date, when information relative to the moisture content of the batch is desired, the tagged electrodes are merely removed from the box and reweighed. The average covering weight is known from the original data of the electrode evaluation. Therefore, any noted changes in total electrode weight can be calculated to per cent change in weight of electrode covering. If carbon

dioxide absorption is considered negligible, the per cent change in weight is primarily due to moisture; the moisture content of the lot represented by the tagged electrodes is then considered as this change plus the original per cent moisture content. It is believed that the weight increase due to carbon dioxide absorption is very small and can be neglected without materially affecting the validity of the procedures. It may be noted that the problem of carbon dioxide absorption is being considered for future investigation.

APPLICATIONS OF MOISTURE CONTENT DETERMINATIONS

Typical variations in the moisture content of an electrode covering over an extended time of storage are shown in Fig. 1. The electrode is a cellulosic-potassium E-6011 type, $^{3}/_{16}$-in. diameter. Humidity in the storage area was recorded continuously by means of a Type R/3 Friez humidity recorder. Six electrode samples were selected from various sections of their respective cartons, identified and weighed. The electrodes were then replaced in approximately the same relative positions and after one week were removed and reweighed. This procedure was repeated over a period of four weeks. The electrodes then were replaced in their respective boxes and after one month they were again weighed. The actual moisture content of each electrode covering was determined at the end of this period by heating at 120° C. (248° F.) for 3 hr., cooling, reweighing and calculating the percentage ratio of the loss in weight to original covering weight.

The graphs of Fig. 1 indicate that the six sample electrodes exhibited similar tendencies to gain or lose weight throughout the two-month period. In addition, there appears to be a significant agreement between the covering moisture content and the storage area humidty conditions.

Results of a survey conducted on two brands of low hydrogen type electrodes are shown in Fig. 2. As indicated therein, the procedure was successfully used to study the moisture variation that occurred. An analysis of these data indicates that, in respect to per cent moisture change, there is no appreciable difference between electrodes 1 and 2 for each brand. In addition, the data indicate that there is a relationship between per cent moisture changes of both brands throughout the period of July 15, 1948, to Oct. 1, 1948. This latter conclusion is supported by a correlation coefficient of 0.6894 for average per cent change during the period indicated.

The method was also used to follow the moisture content of batches of $^{3}/_{16}$-in. sizes of E-6010 type electrodes submitted for evaluations. Moisture contents and covering weights were determined, and sample electrodes were weighed and identified in accordance with the procedure

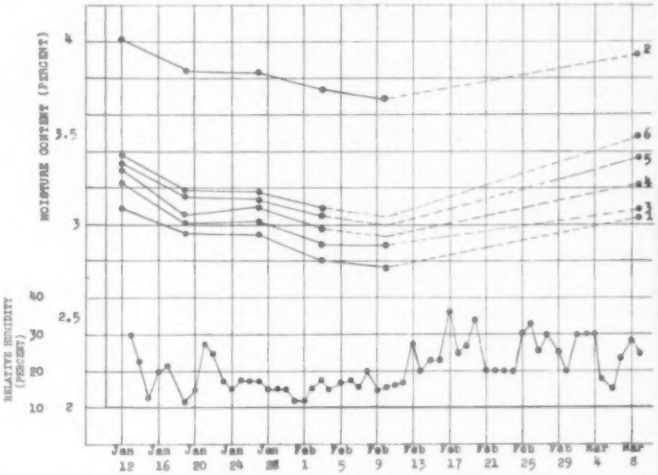

Fig. 1 Relationship between variations in electrode covering moisture content and humidity changes, E6011 type, $^{3}/_{16}$ in. diameter

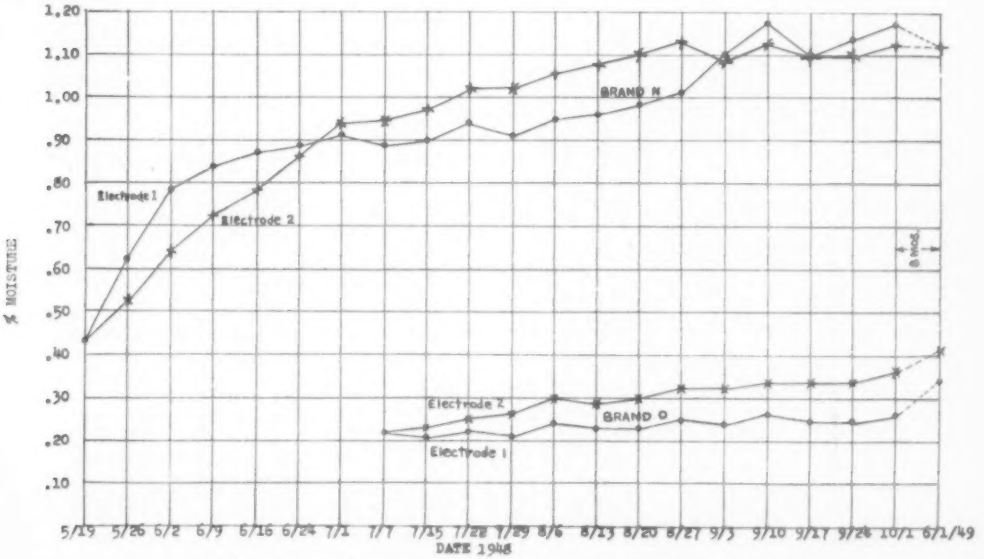

Fig. 2 Variation in moisture contents of electrode coverings, E7015 type

outlined above. The weights of the sample electrodes were again determined at the beginning of the E-6010 evaluation program. Results of these observations are shown in Table 1. To check the increases in moisture contents noted, samples of three of these brands were rechecked for moisture by heating; the values obtained have been listed in Table 1 as "actual" moisture. As indicated therein, these values are in substantial agreement with those calculated on the basis of original moisture content plus weight gain of electrodes.

The contemplated procedure for the application of these moisture variation determinations to electrode evaluations might be as follows:

(*a*) In those instances where fillet usability results indicate that the $^3/_{16}$-in. size is not satisfactory, an attempt would be made to restore the moisture content to that originally present in the electrodes as received, and limited usability tests will be conducted to note any improvement in weldability properties.

(*b*) In those cases where an abnormally high increase in weight is noted for the $^3/_{16}$-in. size, the condition of all sizes of the brand received at the same time and stored under similar conditions would be suspect and moisture determinations would be conducted on all sizes.

(*c*) In the event that moisture contents of the electrodes show a marked deviation from what would normally be expected and the electrodes show poor usability characteristics, retests would be conducted on samples of the electrodes which have been treated in an attempt to restore the original content of the $^3/_{16}$-in. size.

1. Should these retests yield satisfactory results, sufficient electrodes would be processed for conducting all tests required.
2. In cases where electrodes continue to exhibit poor usability, the manufacturer would be so informed, and new samples would be requested.

It is realized that the procedure could be improved by the determinations of changes in moisture content of all sizes. However, original observations were restricted to the $^3/_{16}$-in. size only for reasons of economy.

PHYSICAL METHODS OF COVERING ANALYSES

In the course of research and development investigations as well as evaluations of welding electrodes, it became obvious that a rapid, economical method of indicating the constitution of electrode covering would be highly desirable. Such a procedure could facilitate studies of the peculiarities in performance which are encountered with commercially available electrodes, as well as studies of the relationship between electrode covering constituents and weld deposit characteristics.

In cases of evaluations, the method could be utilized to secure original analytical data which can be rechecked to ascertain whether or not comparison inspection samples representative of production batches are similar to those originally submitted.

Wet chemical methods have been the most widely used to determine most of the constituents. However, aside from the time and expense involved, these

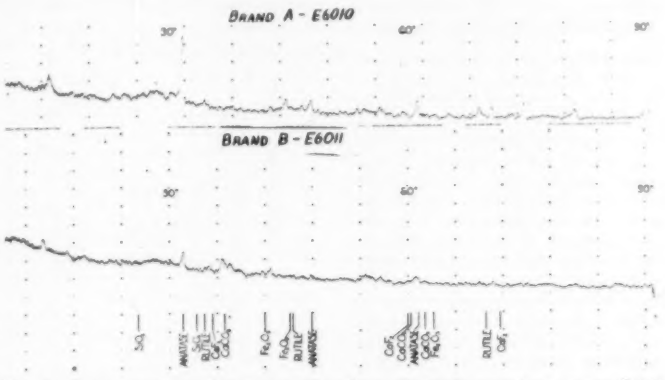

Fig. 3 X-ray spectrometer traces of various electrode coverings, types E6010 and E6011

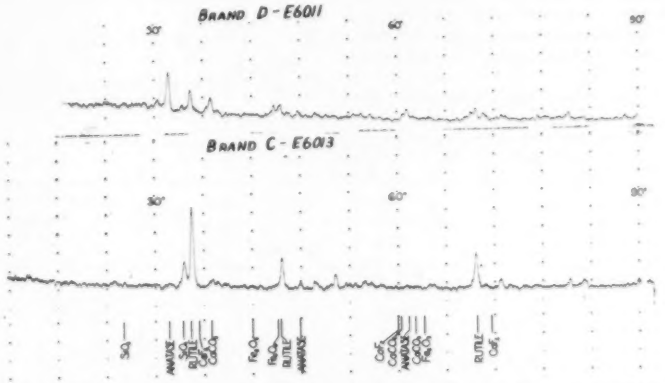

Fig. 4 X-ray spectrometer traces of various electrode coverings, types E6011 and ND-E6013

Table 1—Change of Moisture Content of Electrodes in Storage

Electrode brand		*Q*	*S*	*T*	*U*	*V*	*W*	*Y*	*Z*	*AA*	*BB*	*CC*	*DD*
Wt. increase, gm.%	Electrode 1	0.040	0.020	0.025	0.073	0.046	0.055	0.050	0.041	0.006	0.053	0.040	0.020
	Electrode 2	0.040	0.018	0.023	0.076	0.043	0.055	0.051	0.038	0.008	0.048	0.030	0.030
2/1/49 to 6/2/49	Electrode 3	0.030	0.020	0.037	0.077	0.046	0.052	0.055	0.027	0.007	0.056	0.030	0.036
	Av.	0.037	0.020	0.028	0.075	0.045	0.054	0.052	0.035	0.007	0.052	0.033	0.029
Wt. coating, gm.		4.46	5.58	4.37	5.29	7.27	5.77	5.34	4.80	5.24	5.04	8.64	7.09
% Increase		0.83	0.36	0.64	1.42	0.62	0.95	0.98	0.73	0.13	1.03	0.38	7.09
Moisture, %, 2/1/49		5.0	5.7	5.1	3.6	3.1	7.0	5.4	4.4	2.5	6.0	6.4	5.3
Calc. moisture, %, 6/2/49		5.8	6.1	5.7	5.0	3.7	8.0	6.4	5.1	2.6	7.0	6.8	5.7
Actual moisture, %, 6/2/49		...	...	...	4.5	3.7	...	...	...	2.8	...	...	...

analyses are considered to be inadequate because they do not indicate the compounds and crystalline forms present. It is a known fact that two coverings yielding similar chemical analysis results but composed of different crystal forms can have different properties. For example, titania (TiO_2) may be introduced into a covering as rutile, anatase or, in combination with iron, as the cheaper ilmenite ($FeTiO_3$). Each form will introduce particular properties into the covering, and the aliquot substitution of one for the other will not necessarily yield equivalent results.

The consideration of the above presented the following related problems:

(*a*) Development of a suitable method for a "fingerprint" identification of electrode coverings so that over-all similarities or differences in composition and crystalline forms might be detected between the coverings of electrodes submitted for evaluations and subsequent comparison inspection samples supplied from production runs.

(*b*) Development of a suitable method of analysis which would provide qualitative and quantitative information as to mineral constitution of electrode coverings.

X-Ray Spectrometer Method

The purpose of this portion of the investigation was to determine the extent to which the X-ray spectrometer, described by Friedman[8] could be used to furnish a rapid means of qualitative and quantitative identification of electrode coverings. The feasibility of classifying coverings by means of comparison with patterns taken on samples of known types was investigated, and the forms of major constituents in the coverings were determined. In addition, some preliminary work was done to set up working curves for quantitative estimation of two of the covering components in the crystal forms indicated, namely anatase (TiO_2) and alpha quartz (SiO_2).

The equipment used in this work was a North American Philips X-ray spectrometer, and all the patterns were taken using Fe K Alpha radiation, and were recorded on a Brown recorder, at a scanning rate of one r.p.m.

Qualitative

The specimens were prepared by grinding the coverings until the powder passed through a 200-mesh screen. The powder was then mixed with ethyl alcohol to make a thick slurry which was applied to a glass microscope slide with an eye dropper to form a uniform coating of the sample on the slide. After evaporation of the alcohol the powder adhered to the slide, so that it could be handled easily.

In order to be able to make direct comparison between traces, each was taken under the same conditions of exposure. Ninety-degree traces were taken on all coverings, while only portions of the traces which contained the most intense SiO_2 and TiO_2 lines were taken in the case of the standards.

Examination of the traces (Figs. 3–7) of eight coverings shows that there are significant differences among them. It was found that a single trace on a covering was sufficient to determine which of the eight types it was.

Figure 8 contains two traces of different batches of the same brand and size of electrode. One trace represents samples submitted for evaluation and the other represents a sample which was submitted by an inspection activity for comparison inspection tests. An examination of these traces indicates that the constitution of the two coverings is similar.

Figures 9 and 10 represent traces of different brands of electrodes of the same type. As indicated therein, while there is

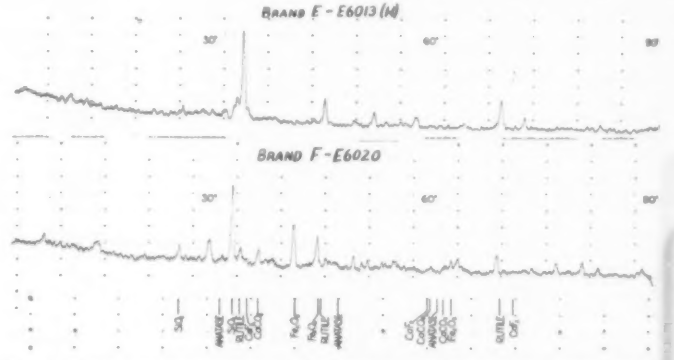

Fig. 5 X-ray spectrometer traces of various electrode coverings, types E6013H and E6020

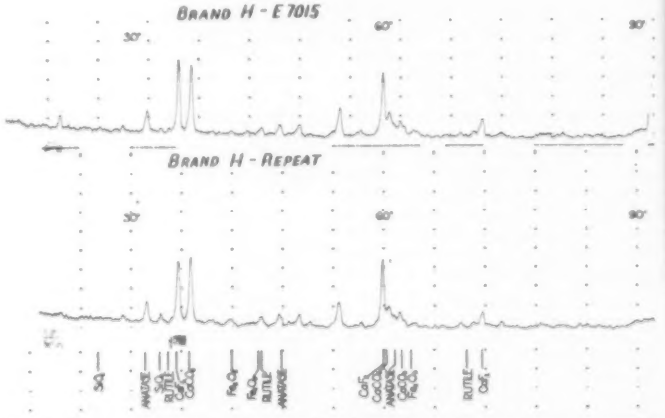

Fig. 6 X-ray spectrometer traces of various electrode coverings, type E7015

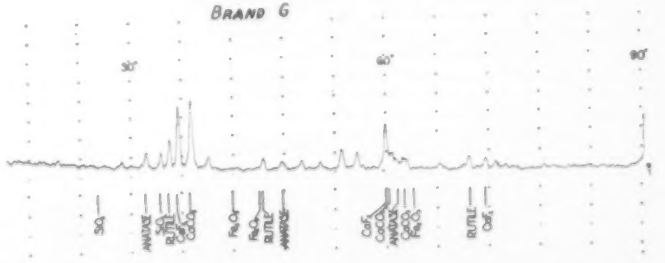

Fig. 7 X-ray spectrometer traces of various electrode coverings, experimental type

an over-all similarity, sufficient individual differences are present to differentiate one from the other. The traces of Fig. 10 represent coverings of the same composition which were used on two different brand numbers of the same electrode type (Code L and M) and exhibit a degree of similarity which is considered to be significant. The manufacturer has stated that these electrodes differ in covering thickness only.

The major components of each covering may be readily identified by the location and intensity of the X-ray reflections for each coating. Table 2 shows a list of the

Table 2

Fig. No.	*A.W.S. designation covering*	*Components detected*
1.	E6010	TiO_2 (anatase), TiO_2 (rutile)
2.	E6011 (1)	TiO_2 (anatase)
3.	E6011 (2)	Anatase (TiO_2), rutile (TiO_2), $CaCO_3$
4.	E6013	Rutile, quartz
5.	E6013	Rutile, quartz
6.	E6020	Quartz, Fe_2O_3
7.	E7015 (1)	$CaCO_3$, CaF_2, anatase (TiO_2)
8.	E7015 (2)	$CaCO_3$, CaF_2, anatase (TiO_2), rutile (TiO_2)

coverings run, and the compounds identified in each one. For rapid identification of the compounds, a scale was made on which the major reflections of the principal crystalline ingredients were plotted in the positions in which they occur under the conditions of recording used throughout. Thus by comparison of the scale with the traces, the major reflections can be readily identified. This scale is shown in place below the traces of the coverings (Figs. 3–10); all the reflections could be read directly. This scale has been found suitable for general use in identification work with the X-ray spectrometer and has been described by Foster.[7]

Quantitative

The standards used for establishing the working curves were prepared in the following manner. An average composition was determined for coverings of types E-6010, E-6011 and E-6013. These coverings were chosen since they are similar in nominal composition. The mean composition of these coverings was found to be about 45% of SiO_2 and TiO_2 and about 55% of the remaining compounds. A matrix was made consisting of the mean percentages of the following compounds in the five coverings: K_2CO_3, Na_2CO_3, $CaCO_3$, Al_2O_3, FeO_3, MgO and MnO_2. This matrix was mixed by grinding, and was sieved until it all passed through a 200-mesh screen. One gram of each standard was made by adding 550 mg. of this matrix to 450 mg. of mixtures of SiO_2 and TiO_2. The proportions of SiO_2 and TiO_2 were such that their percentages in the final mixtures were 0, 7½, 15, 22½, 30, 37½ and 45%. Mixing was accomplished by grinding for one hour. The standards were then mounted in glass slides using a technique similar to that described previously.

Five slides were prepared for each of the standards as described previously. Readings were taken on two different spots on each slide, and the averages of these ten readings were plotted for quartz and anatase, using peak intensities over background as ordinates against per cent as ab-

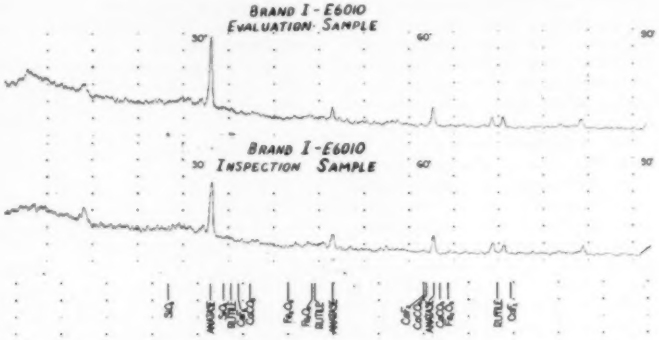

Fig. 8 X-ray spectrometer traces of two batches of the same brand, type E6010

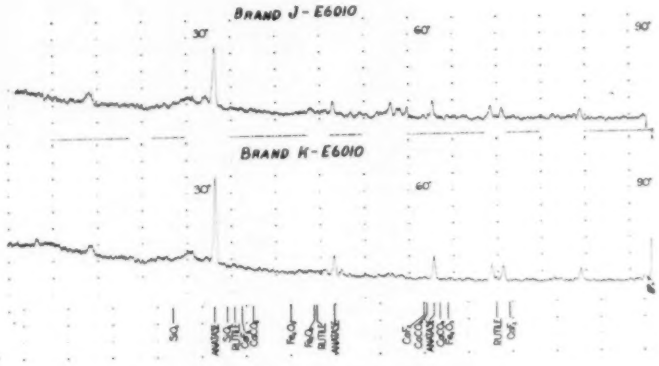

Fig. 9 X-ray spectrometer traces of two brands of E6010 type

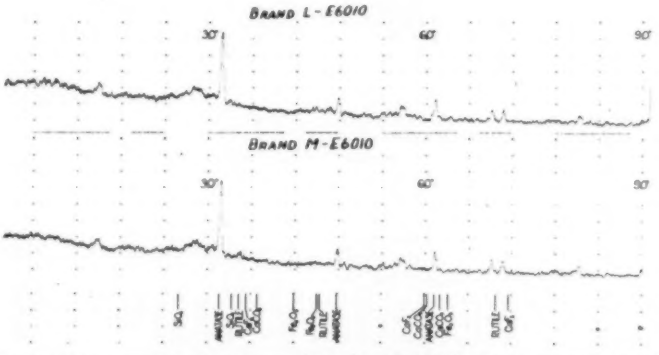

Fig. 10 X-ray spectrometer traces of two brands of E6010 type, composition of coverings identical

Table 3

Compound	*Crystal form*	*Equation intensity vs. %**	*Correlation coefficient*	*Std. Error† of estimate in % of conc.*
SiO_2	Quartz	$Y = 12.80 + 21.76X$	0.9953	1.33
TiO_2	Anatase	$Y = 31.53 + 7.36X$	0.9710	3.87

* Y = Intensity units; X = Per cent.
† Based on the average of ten readings of five different specimens.

scissa. For the range studied the relation appears to be approximately linear. Data descriptive of the resulting analytical working curves together with an estimate of precision is shown in Table 3.

DISCUSSION OF X-RAY SPECTROMETRIC METHOD

Reproducibility of X-ray spectrometer intensities of a sample which is compared to a standard depends upon three important considerations. The sample must be uniform, have random particle distribution and comparable absorption characteristics. For this reason, some remarks on the characteristics of X-ray reflections as affected by absorption, segregation and orientation are pertinent. A pure substance which is randomly oriented will give a series of reflections of varying intensities which is characteristic of the substance. In a mixture of two or more substances, each will scatter independently of the other so that the resultant pattern will show the reflections of one substance superimposed upon those of the other, and the intensities of the reflections will be proportional to the amounts of the materials present in the mixture. However, absorption is an important factor in determining the intensity of a reflection of a given substance in a mixture. Thus a given percentage of a material in a highly absorbing matrix will not reflect as strongly as a similar percentage in a low absorption matrix.

Both orientation and segregation of components in a mixture will tend to give intensities of an erroneous nature. These are believed to be the most important factors affecting the reproducibility of intensities, therefore efforts must be made to devise techniques which would minimize these effects.

Indications are that both orientation and segregation effects are lessened by increasing the grinding time. However, the grinding must be controlled to prevent the particle size from becoming too small, as line broadening results when particles are smaller than one micron. Another difficulty arises when grinding a mixture of relatively hard and soft components, as is the case with quartz and titania, where the particle size of the latter is reduced more rapidly than that of the silica.

Several different methods of preparing flat specimens for the spectrometer were studied. Of the methods tried, the most consistent results thus far obtained required using a thick slurry of alcohol and the powder, as described previously.

In recording a complete pattern for a material, the rate of scanning affects the reproducibility of the pattern. As the scanning rate is reduced, reproducibility is increased, but the time necessary for recording a complete pattern is increased; thus the 1 r.p.m. scanning rate may be considered a compromise between speed and accuracy, and appears to be adequate for qualitative work. For quantitative work, it is expected that greater accuracy may be attained by using slower scanning speeds or by taking counts through the diffraction maxima. In addition it is felt that the effect of orientation and segregation can be overcome tentatively by taking readings on several different samples, as was done in setting up working curves for titania and silica. Further improvements in this connection might be made by employing a rotating sample holder.

It has been pointed out that the intensity of a given component in a multicomponent system depends to some extent on the nature of the other components. Consequently for improved precision, separate working curves may have to be set up for each of the covering types.

From the reflections recorded on the patterns, it is possible not only to determine the chemical compounds producing these reflections, but also the crystal form of these compounds. For example, TiO_2 may be present as either anatase or brookite which are the same materials chemically but have different crystal forms and consequently different diffraction patterns. In addition, the physical properties of the two forms are not the same, since it has been reported that differences in crystal form may affect the welding properties of the electrodes. Thus changes in source of materials or methods of manufacture of a particular covering may be detected by this method.

Some compounds present in low concentrations influence the traces derived; however, only their stronger lines appear as peaks slightly above background and do not lend themselves to quantitative estimates. Their weaker lines are submerged in the background which is derived from various miscellaneous radiations present in the environment and variations in equipment responses. Since only one or two of the strongest lines appear distinct from the background, and since several lines generally are required for mineral identification, such identification cannot readily be made. However, the stronger lines do appear as peaks above the background and yield a characteristic pattern which can be used for comparison ("fingerprint" identification). As was indicated above, a method may be developed for positive identification of the minerals present in low concentrations.

Optical Spectrographic Methods

This portion of the investigation dealing with establishment of spectrographic methods of analysis of the electrode coverings was carried on for the purposes of assisting in rapid identification of various types and brands supplied, to supplement information obtained by the X-ray spectrometer. The spectrographic techniques should be of particular value in the determination of minor elements since X-ray diffraction methods usually cannot detect these constituents, which nevertheless may be of considerable importance in the functioning of the coverings.

Equipment Used. A Bausch and Lomb large Littrow spectrograph, a 220-v. d.-c. arc excitation source and a Leeds and Northrup a.-c. recording microphotometer were used in this work.

The method was developed to utilize samples to which 19 parts of CuO and 20 parts of NH_4Cl are added to 1 part of sample. After mixing, the samples are further homogenized by grinding to 200 mesh with the aid of a mechanical mortar and pestle.

A group of synthetic standards was prepared with CuO as the base material. Additions of various compounds were made to each standard in amounts containing equivalent percentages of the metallic elements as listed in Table 4. These percentages when multiplied by factors for conversion to the particular oxide involved and to correct for the dilution of samples with CuO, cover the usual range of constituents found in subject coverings. An equal amount of NH_4Cl was added to each standard and a grinding procedure,

Table 4—Percentage Metallic Elements in CuO-NH_4Cl Matrix

Std.	*Cu*	*Ti*	*Li*	*K*	*Na*	*Ca*	*Al*	*Fe*	*Mg*	*Mn*
0	100.00	...	...	...	...	...	...	...	...	...
1	R	0.40	0.80	0.05	0.03	0.03	0.02	1.00	0.03	1.00
2	R	0.80	0.40	0.15	0.15	0.07	0.15	0.50	0.15	0.50
3	R	1.60	0.20	0.35	0.30	0.15	0.25	0.08	0.25	0.25
4	R	1.20	0.30	0.25	0.45	0.10	0.10	0.25	0.05	0.15
5	R	0.20	0.60	0.50	0.08	0.10	0.05	0.15	0.10	0.35

similar to that of the samples, was followed.

Operating Conditions. Five 40-mg. portions of each of the synthetic powder standards were run in a direct current arc at 10 amp. for 45 sec. after an initial preburn period of 10 sec. at 4 amp. The Bausch and Lomb large Littrow spectrograph was employed using quartz optics at the spectral region 2490–3450 Å. (Q5) and a slit width of 25 m_μ, with a 4-mm. analytical gap placed 18 in. from the slit. A 200-mesh screen was placed in front of the slit. An Eastman Kodak SA1 plate was used in recording the spectra. A standard method was employed in development using D19 for 5 min. at 65° F. The densities of the various line pairs were read with a Leeds and Northrup microphotometer.

Results. Analytical working curve data for six elements in coverings studied were compiled in Table 5. These working curves were based upon the averages of five observations of delta log I values corresponding to each synthetic standard used. The regression equation associated correlation coefficient, and standard errors of estimate of reported content (S_{XY}) for each line pair are included.

Based on these analytical working curves it is possible to obtain quantitative results for the elements Al, Fe, Mg, Mn, Si and Ti, with the precisions listed. It should be noted that the high value for Mg (13.13%) probably can be tolerated for purposes of identification when one considers the fact that the percentage range for the element (0.6–5%) is rather low compared to elements such as Si or Ti. The analysis of the coverings is based on the working curves described. A test of accuracy of results can be made by the inclusions of similarly prepared samples of ceramic materials certified by the National Bureau of Standards.

Discussion of Optical Spectrographic Technique

The spectrographic analysis of such materials as welding electrode coverings presents difficulties not usually encountered with materials investigated by such methods. The coverings contain several elements in major amounts so that effectively they have no relating constant matrix metallic compound. Furthermore the compounds and crystal forms in which the elements occur vary, as evident, for example, from the fact, determined by X-ray spectrometer analysis, that Ti occurs in two crystal forms of TiO_2 as well as in the ilmenite form. The difference in forms in which an element occurs gives rise to marked changes in its intensity ratio for a given percentage. The use of cupric oxide and ammonium chloride in the preparation of the samples and standards was based on the above consideration. Cupric oxide has been introduced as a matrix material to provide the metal Cu for use as an internal standard. It also acts as a diluent, reducing the high percentages of constituents, thereby making possible the application of ordinary techniques of spectrographic analysis to these coverings. The NH_4Cl is used as a flux to change the various compound forms in which elements may occur to a common basis as well as to expedite the burning rate of the refractory materials. Its beneficial effect in the latter respect has been observed from dropping plates run on samples with and without NH_4Cl.

Because of the great dilution factor used, the amount of original sample actually used in an analysis is very small. Consequently care in the preparation of standards and samples to obtain uniformity is of great importance. With the sample preparation technique utilized in the work to date it is considered that a minimum of five runs should be made to obtain representative sampling with the precision indicated.

Cupric oxide has been used here as buffer-diluent since its effectiveness in this respect has been reported in connection with ceramic analysis.[8] However, preliminary burning rate studies indicate that improvement in the control of the unknown element lines which Cu provides could be desired. Consequently other diluents such as Li_2CO_3 and SiO_2 might be investigated. The use of TiO_2 and SiO_2 as diluents would require that the analysis of Ti and Si, respectively, be made by other means, as for example by the use of the X-ray spectrometer, which has shown encouraging results.

To overcome the need of 5 runs to compensate for segregation effects which accompany the use of small samples burned in the d.-c. arc, sample compacts which may be rotated by mechanical means and excited by spark methods will be investigated. For this purpose special adapters to the conventional Petrey type spark stand have been designed and are now under construction. The effectiveness in providing integration of sample inhomogeneity will be reported in a future paper.

Table 5

Element	*Line pair**	*Regression equation,† Y or X*	*Percentage range, as oxides*	*Correlation coefficient*	*Standard error of estimate in % of content, S_{xy}*
Al‡	2575.10/3146.82	$Y = -0.344 + 0.710\,X$	1–10	0.9916	8.8
Al	3082.16/3073.80	$Y = -0.767 + 0.765\,X$	1–10	0.9991	5.0
Fe	2973.13/3146.82	$Y = -0.302 + 0.312\,X$	1–25	0.9966	9.9
Mg	2779.29/3146.82	$Y = -0.568 + 0.671\,X$	1–8	0.9921	13.1
Mn	2933.06/3146.82	$Y = -0.312 + 0.757\,X$	7–12	0.9998	1.8
Si	2987.65/3146.82	$Y = -0.688 + 0.694\,X$	20–30	0.9950	7.4
Ti	3075.22/3073.80	$Y = -0.475 + 0.624\,X$	15–55	0.9997	2.8

* Cu is used as the matrix element.
† $Y = \Delta \log I$; X = log per cent.
‡ Al 2575.10/3146.82 is better for the higher end of percentage range whereas 3082.16/3073.80 is more suitable for the lower range, although the curves may be used for the entire range with precisions indicated.

SUMMARY

The work reported above has resulted in the following developments:

(*a*) A method for following the moisture changes which occur in electrode coverings in storage. This procedure has been applied to the study of moisture changes encountered in samples received for evaluation.

(*b*) An X-ray spectrometer "fingerprint" method for rapid classification of electrode coverings into types. Traces of the coverings of electrodes recommended for acceptance as a result of evaluations could be made which might serve as comparison standard for future inspection tests of the same brand. This method is capable of revealing major deviations in source of material or methods of manufacture for a particular brand of covering from that originally submitted for qualification.

(*c*) An X-ray spectrometer method for determining crystal forms and amounts in which titania and silica are introduced into electrode coverings. The method would be useful for the comparative tests indicated above as well as in research investigation of electrode coverings and their resulting weld metal deposits. The precision obtainable by averaging of readings to compensate for orientation and segregation effects are 1.3 and 3.9% of the reported content for SiO_2 (alpha quartz) and TiO_2 (anatase), respectively.

(*d*) Optical emission spectrographic methods for the quantitative determination of metallic elements to supplement information furnished by X-ray spectrometer methods. These hold promise of providing a convenient method for the determination of low concentration metallic constituents regardless of crystalline form. Preliminary analytical working curves for Al, Fe, Mg, Si and Ti indicate the determination of these elements may be made with precisions of from 3 to 13% of reported content.

ACKNOWLEDGMENT

The authors wish to acknowledge the cooperation and assistance of I. L. Stern, H. Nagler and B. Hershkowitz, Welding Engineers in the Welding Development Section, and F. Bernstein and H. Levine, Physicists in the Emission Spectrography and X-Ray Diffraction Section, Material Laboratory, New York Naval Shipyard, in securing the data presented herein. Encouragement of this work, and review of the paper by N. A. Kahn, Head of the Metallurgy Branch, is appreciated. Permission by the Navy Department to publish this work is gratefully acknowledged.

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Notch Sensitivity of Welded Steel Plate

Discussion by F. J. Winsor

THE latest contribution of Professors McGeady and Stout is another valuable addition to the knowledge of the notch sensitivity of welded steels. The authors are to be complimented for their efforts to provide further basic information on this problem without losing sight of the practical aspects. It is hoped that the following comments, by encouraging further analysis and explanation of their data, may provide additional valuable information.

First, do the authors have an explanation for the fact that, as shown by the data in Table A, welding produces a much greater increase in transition temperature for the A201 steel than for the A212 steel?

Table A

Type	*Thickness, in.*	*Ductility, Transition temp. – ° F., as-rolled*	*Transition temp. – ° F., welded 10 in./min.*	*Increase in transition temp. by welding ° F.*
B201	5/8	–90	55	145
B201	1	–120	40	160
B212	5/8	–30	0	30
A212	5/8	–50	–50	0
B212	1	10	100	90
A212	1	–80	0	80

According to Table I, which shows the chemical analyses of the steels, the A201 heat had lower carbon and manganese contents and a higher phosphorus content than the A212 heats. Could it be that an increase in phosphorus content of only 0.007% is more effective in promoting notch sensitivity after welding than increases of as much as 0.15% of carbon plus 0.35% of manganese? This causes one to wonder what effect welding might have on the transition temperature of an A201 steel containing only 0.013% phosphorus rather than 0.020%. It appears that phosphorus might be more effective in causing embrittlement after welding than in increasing the hardness, and decreasing the ductility, of the ferrite in as-rolled steel.

Has the possibility been considered, also, that welding might cause precipitation of a phosphorus-containing constituent, either in the heat-affected metal or in regions farther from the weld which receive some heat from welding but not enough to raise the temperature above the critical? Other investigators[1, 2] have reported that regions heated to temperatures below the critical temperature during welding suffer a marked decrease in notch toughness. Relative to this, has the improvement in ductility brought about by post-heating at 1150° F. been found to be independent of the cooling rate following the 1150° F. heat treatment?

Second, it is noted that the authors found no correlation between the transition temperatures of the steels and the manganese/carbon ratio. From our knowledge of the matter it appears that such a correlation is possible only when the comparison is made for mild steels having equivalent tensile strengths and made with reasonably similar deoxidation practices. In view of the fact that manganese is both a ferrite strengthener and a hardenability promoter it is not surprising that no improvement in notch toughness is realized by increasing the manganese content while the carbon content remains constant. However, the work of Barr and Honeyman[3] indicates that the notch toughness is improved by decreasing the carbon content in order to maintain equivalent tensile strength as the manganese content is increased. Data from their work are shown in Table B.

Third, the authors report that no correlation existed when 40 ft.-lb. energy absorption was used as the transition-temperature criterion in V-notch Charpy tests and compared to the longitudinal bend-test data. It is realized that such a correlation might not be

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The paper by L. J. McGeady and R. D. Stout was published in the Supplement to The Welding Journal, pp. 243-s to 251-s, May 1950.

Table B—Effect of Manganese/Carbon Ratio on TransitionTemperature of Mild Steel[2] (Normalized at 1650° F.)

Heat No.	Chemical composition C, %	Mn, %	Si, %	Mn/C ratio	Yield strength, psi.	Ultimate strength, psi.	Elongation, % in 2 in.	Reduction of area %	Fracture transition temp. range, ° F.
1229	0.19	0.27	0.12	1.5	32,800	55,800	39	61	+19 to +100
1230	0.17	0.68	0.13	4.0	37,800	57,800	40	66	−33 to +32
1278	0.115	0.89	0.13	7.7	38,800	57,400	42	66	−58 to −18
1232	0.10	1.19	0.15	11.9	38,200	56,800	42	73	−65 to −49

possible. However, we wonder why an energy level of 40 ft.-lb. was selected for the comparison and whether there might have been a better correlation had some lower value of energy been selected. It would appear more appropriate for comparison purposes to select an energy level which gives transition temperatures more nearly in the range of those determined by the 2% lateral contraction criterion in the bend test.

Fourth, was the same class electrode used for welding all of the grades of steel which are listed? Have the authors determined whether a change in tensile strength of the weld metal deposited in a given material has any effect on the transition temperature?

Fifth, the welding industry should be interested very much in the authors' results showing no effect on the notch toughness due to residual stresses produced by welding. A notable scarcity of factual evidence on the effects of residual stresses on the properties of welded joints has been reported in the literature. It has been our opinion that, in most cases, improvements in weld properties effected by postheating are the result of metallurgical changes, the relief of residual stresses being incidental. Welds in mild steel, which are subject to corrosive attack by caustic or nitrate solutions, appear to be a notable exception, since this type of cracking usually is considered to be a stress corrosion phenomenon. However, even in this case it is possible that the metallurgical changes produced by welding, as well as the residual stresses, have an appreciable effect on the stress corrosion cracking. Discussion of this problem certainly is scarcely related to the subject of notch sensitivity of steel. However, it is mentioned because the authors' restraint-type weld specimen, in which known amounts of residual stress can be incorporated into the test specimen, could well be employed for determining the effects of residual stresses on other properties of welded joints, in addition to notch toughness.

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Authors' Reply

The comments of Mr. Winsor are greatly appreciated by the authors.

Mr. Winsor points out that the higher carbon and manganese A212 heats were less affected by welding than the A201 plates. Additional work is required (and is planned) to show why such results were obtained. At present it appears that mill practice may introduce the differences that were found. The effect of phosphorus variations within specifications has not previously been studied on welded plates, and may be more important than previously realized. Mr. Winsor suggests an interesting possibility as to the mechanism of the action of phosphorus. Cooling rates following 1150° F. postheating were restricted to air cooling in the investigation.

Mr. Winsor confirms the point stressed by the authors about the manganese to carbon ratio. Lowering the carbon content leads to improvement in notch toughness of steel, whether it is made possible by adding manganese, nickel, chromium or other alloys to retain tensile strength. Perhaps a more significant ratio to consider would be the tensile strength to carbon ratio.

In answer to the discussor's question concerning the correlation between Charpy and slow-bend transition temperature, the 40 ft.-lb. level was chosen as the inflection point on the Charpy curve. Recent work indicates a value of 15 ft.-lb. as more significant, but as examination of Figs. 12 and 13 in the paper will show, this new level does not improve the correlation.

One batch of E6010 electrode was used for all weld deposits. In previous work variation of the electrode class was shown to have a negligible effect on transition temperature. A slight lowering of transition was observed when austenitic electrodes were used.

The authors wish to thank Mr. Winsor for his discussion.

Electrode Tip Life in Spot Welding Galvanized Steel

Effect of a long series of spot welds upon the electrode tip and the characteristics of the weld

by Frank W. McBee, Jr.

SPOT welding is primarily a tool of mass production, consequently any study concerning the use of this process is incomplete unless it includes the application of the process to production techniques. During the past few years there have been made at the University of Texas several coordinated investigations on spot welding of galvanized steel. These investigations have included the selection and determination of the proper conditions for welding this material,[1] together with recommendations for the proper selection of electrode tips.[5] The major portion of these investigations has been conducted under laboratory conditions and has of necessity eliminated the production aspects of the problem.

SCOPE OF THE INVESTIGATION

The purpose of this project was to determine the number of commercially satisfactory spot welds which can be made on 22 gage galvanized steel under a specified set of optimum conditions without tip redressing and to determine the causes for the failure of the weld. In other words, this investigation was an effort to simulate the conditions which exist in industry and to determine the effect of a long series of spot welds upon the electrode tips and the characteristics of the weld.

It was expected that the welds might fail for any of the following reasons or a combination of them: (1) strength, (2) indentation, (3) appearance, (4) excessive flashing or sticking of the components during welding, (5) excessive zinc pickup on the electrode tips.

Furthermore, the investigation was to include any recommendations or remedies for increasing the number of welds possible. The study included the welding of 1.25 oz./sq. ft., 0.0395 in. gage, 1.24 oz./sq. ft., 0.036 in. gage and 1.70 oz./sq. ft., 0.0395 in. gage galvanized steel.

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A partial investigation of the problems involved in making a series of welds was made by M. L. Begeman, *et al.*,[1] whose conclusions indicated that there was essentially no decrease in average weld strength for a series of 100 consecutive spot welds without tip redressing. The electrode tips also appeared to be in good condition after this series.

DESCRIPTION OF EQUIPMENT

Welder

The welding in this study was performed on an Acme 75-kva spot welder, type 3.18.75, style SOAR, using 220 v., 60 cycle, single-phase alternating current. In conjunction with the welder, a model CR 7503-A125 General Electric Thyratron Control Panel was used to control weld time and weld current magnitude. A General Electric Sequence Control Panel, model CR 7503-F, controlled squeeze time, hold time, and off time.

Current Measuring Apparatus

Considerable thought was given to the problem of measuring the current in the weld accurately. From information available, the pointer stop ammeter was assumed to be too inaccurate, while, on the other hand, the use of a recording oscillograph was too involved and expensive if a large number of readings was to be made.[2]

The idea of using a ballistic electrodynamometer was suggested and appeared to have merit. An electrodynamometer is an instrument similar in appearance to a D'Arsonval galvanometer. It contains a movable coil in a field produced by two fixed coils which replace the permanent field in a galvanometer. When used ballistically, the deflection of the moving coil, θ, is

$$\theta = K \int I^2 dt$$

where:

K is a constant
I is the current flowing, amp.
t is the time during which current flows, sec.

Evaluating K, measuring θ and t, the current can be

determined. Such an instrument was constructed by this writer. It received its impulse from a calibrated manganin shunt inserted in the secondary of the welding transformer. An optical system was used to measure the angular deflection.[4]

The results obtained with the ballistic electrodynamometer were quite satisfactory. A portable pointer stop ammeter, Westinghouse type PY 5, was used in conjunction with a current transformer connected to the primary of the welding transformer. The data obtained from this instrument was used as a rough check on the ballistic electrodynamometer.

Physical Testing Equipment

The weld indentation was measured by means of indicating outside calipers. All welds were tested on a Southwark-Tate-Emery 120,000 lb. Universal testing machine. The specimens were held in a pair of Templin sheet-metal grips and loaded longitudinally, causing the primary failure to be in shear.

SELECTION OF WELDING CONDITIONS

The selection of the proper conditions for welding of the specimens was made on the basis of results of previous studies and of preliminary tests made by this writer. These conditions were used in making all of the welds tested: (1) squeeze time—20 cycles, (2) hold time—10 cycles, (3) electrode closing rate—3 ft./sec., (4) throat depth—12 in., (5) horn gap—8 in., (6) electrode cooling water rate—1.5 gal./min., (7) electrode tip pressure—638 lb. net (since dome-shape tips were used, tip pressure became a force), (7) electrode stroke—0.25 in.

In accordance with recommendations by H. B. Spore,[5] a Mallory "3," No. 3527, R.W.M.A. Class II, 2-in. radius dome tip was chosen for the tests of the 1.25 oz./sq. ft. and 1.70 oz./sq. ft. 0.0395-in. gage material. The shape of this tip was modified for the tests on 1.24 oz./sq. ft. 0.036-in. gage material by machining it into a truncated cone with an included angle of 120° and a 2-in. radius dome contact area of approximately $^{13}/_{64}$ in. diameter (Fig. 1).

A weld time of 6 cycles for all tests was chosen as a good mean value after tests with 3 and 4 cycles proved to give erratic results.

Weld currents of 16,000 amp., 15,000 amp. and 14,000 amp. were found to give best results with 1.70 oz./sq. ft. 0.0395 gage, 1.25 oz./sq. ft. 0.0395 in. gage and 1.24 oz./sq. ft. 0.036-in. gage materials, respectively.

MATERIAL PREPARATION

The material used in these tests was furnished by the American Rolling Mill Co. and the Bethlehem Steel Co. All coatings were applied by the hot-dip process, using prime western zinc.

The material, which was furnished in sheets 96 by 36 in., was first cleaned thoroughly with carbon tetra-

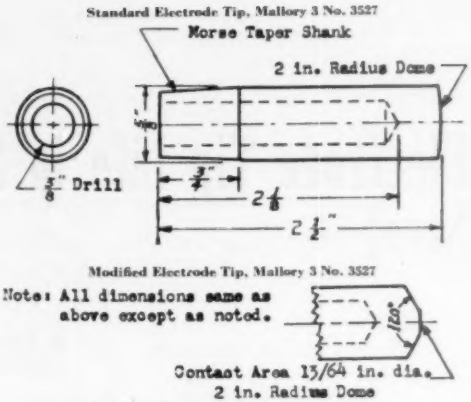
Standard Electrode Tip, Mallory 3 No. 3527
Morse Taper Shank
2 in. Radius Dome
5/8" Drill
3/4"
2 1/8
2 1/2"
Modified Electrode Tip, Mallory 3 No. 3527
Note: All dimensions same as above except as noted.
Contact Area 13/64 in. dia.
2 in. Radius Dome

Fig. 1 Electrode tips used in tests

chloride, then sheared into components 1 in. wide. All specimens used in the test on 1.25- and 1.70-oz. materials were cut to 4.5 in. lengths. In the test on 1.24-oz. coated material, only the test specimens were cut to this length and strips 36 in. long were used to make the intermediate welds.

WELDING PROCEDURE

1.25-Oz. Coated Material

In the test of the 1.25-oz./sq. ft. coated material, the weld procedure was accomplished in the following manner.

The 4.5-in. components were removed from the tray, numbered, and placed in a special jig constructed to facilitate locating the specimens in the welder and to allow uniform overlap and alignment. Then the weld was made. Any flashing or sticking was observed, and a reading of the current was taken every 15th weld. These welds were made in batches of 200 at approximately 40 second intervals. After 200 were obtained, the indentation of every weld was measured—as well as the strength of every 5th weld. This procedure was followed until it became evident that the welds were no longer satisfactory.

1.70-Oz. Coated Material

The procedure for the test on the 1.70-oz. coated material was essentially the same as that for the 1.25-oz. material, with the following exceptions: (1) the test was continuous with no interruptions for the total of 750 welds, (2) the time between each weld was reduced to an average of 10 seconds, and (3) the current was read every 50th weld.

1.24-Oz. Coated Material

The procedure for welding the components used in this test was as follows. Welds number 1 through 10

were test specimens, numbers 11 through 95 were made on strip stock 1 in. wide and 36 in. long. These welds were made with a $^{7}/_{8}$-in. pitch using an off time of 60 cycles, the only interruption being when a new strip was needed.

Welds number 96 through 105 were again 4.5 by 1 in. test specimens. During the welding of the test specimens, a check of the weld current was made, using the pointer stop ammeter.

After each 105th weld, i.e., 105, 205, 305, etc., the conical surface of the cone-shaped tips was dressed in order to keep the contact area at a constant value. (Fig. 1). It should be noted that the contact area or the flat on top of the truncated cone was not dressed during this operation. A special tool was devised for doing this job with the electrode tips in place, which held the time loss for the operation to something less than 30 seconds. The device functioned on the same principle as a simple, old-fashioned pencil sharpener, except for the fact that it was made in two halves which clamped around the electrode tip. The blade for the tool was made of a $^{3}/_{16}$-in. lathe tool bit. Dressing the tip was accomplished by clamping the device in place and turning it by hand. About three turns were necessary to return the electrode tip to its original shape. (In the opinion of this writer, a similar device could be used to advantage in any spot welding job where tip shape is an important factor. Certainly it is a great improvement over the familiar file or emery used in most plants today).

Upon completion of 1000 welds, the indentation of the test specimens was measured, as well as the strength of 5 of the 10 test specimens made after each 100 welds.

INTERPRETATION OF RESULTS

The results of the three series of consecutive welds on galvanized steel are presented graphically and pictorially in the following pages; they can best be discussed under the headings, (1) strength of the weld, (2) weld current, (3) weld indentation, (4) condition of the electrode tips and (5) appearance of the weld.

Strength of the Weld

In Fig. 2 a log of the average strength of the weld is shown for each of the three materials used. In each case the average strength of a number of welds is plotted for each 100 welds.

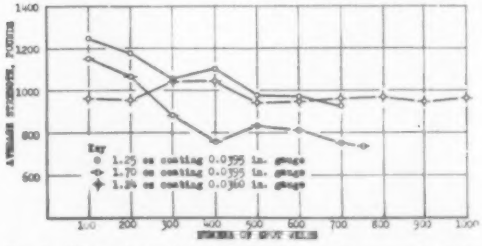

Fig. 2 Effect of a series of spot welds on the strength of the weld

Welds on 1.24-oz. coating 0.0360-in. gage material were made using modified tip

These results may best be described by grouping the 1.25- and the 1.70-oz. coated materials together, since they were both made with the 2-in. radius dome-shaped tip. In both cases, the strength of the weld decreases as the number of welds increases. However, after approximately 400 welds, the rate at which this decrease in strength occurs is less than in the previous 400. The data also revealed an additional fact which is not evident from the log—that the individual strength of the weld became extremely erratic after about 500 welds were made.

The cause of this decrease in strength and the erratic results was presumed to be the increased contact area of the electrode tip together with the possibility of excessive zinc pickup and zinc penetration in the tip. The increase in contact area apparently caused a decrease in current density, and consequently a less penetrating and satisfactory weld.

The type of failure which occurs is important in spot welding, a tear failure being preferable to a shear failure. In the test on the 1.25-oz. coated material, there were 26 plug failures in the first 340 welds, 22 of these in the first 300 welds. All of the welds after the 340th failed in shear. In the test on the 1.70-oz. coated material, there were 24 tears in the first 250 welds and only one in the remaining 500.

In an effort to eliminate the increase in contact area, a series of welds was made on the 1.24-oz. coated material using the modified tip shown in Fig. 1. These tips were dressed after each 100 welds in the manner previously described. The results of this test show that the primary cause of the decrease in strength was the increase in contact area and that the zinc pickup had little or no effect.

As can be seen by the log, the strength of these welds was quite uniform and held up remarkably well for the entire 1000 welds. Further, all of these welds failed as a tear.

A comparison of the strength curve for the three materials welded shows that the 1.25-oz. 0.0395-in. gage material had the highest failing load for the first 100 welds, while the 1.70 and 1.24-oz. coated materials failed at slightly lower values. This can be accounted for in the case of the 1.70-oz. coating by the fact that the gage of the material includes the galvanized coating. The 1.24-oz. coated material was of a slightly lower thickness than the other two.

Weld Current

At the inception of these tests it was thought that zinc pickup might cause an increase in contact resistance and a consequent decrease in weld current. This, however, was not the case—as was substantiated by data from both the pointer stop ammeter and the ballistic electrodynamometer. In all cases, the current remained at a constant value with a slight weld-to-weld variation.

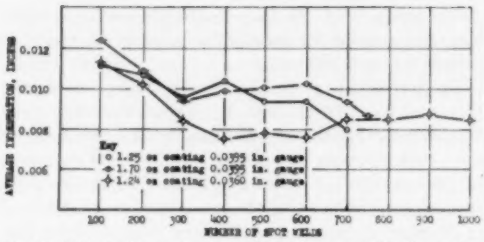

Fig. 3 Effect of a series of spot welds on weld indentation

Welds on 1.24-oz. coating 0.0360-in. gage material were made using modified tip

There was, though, no general trend to decrease as the number of welds increased.

Indentation

The average indentation for each series of welds is shown in Fig. 3. The indentation for the 1.25- and 1.70-oz. coatings followed the same trend as did the strength of the welds: as the number of welds increased, the indentation decreased. The indentation of the 1.70-oz. coating was slightly higher in general than that for the 1.25-oz. coating, as should be expected.

The fact that the indentation decreased indicates that there has been a flattening of the tips or an increase in the contact area. The use of large area flat tips is a well-known method of decreasing indentation.[3]

In the case of the 1.24-oz. coated material, the indentation decreased to approximately 300 welds—then remained about constant for the remainder of the test.

Condition of Electrode Tips

One of the possible causes for the failure of the weld was assumed to be excessive zinc pickup on the electrode tips. This, however, proved to be of little or no consequence, since the visible zinc pickup increased to approximately 50 welds and thereafter appeared to remain constant in all cases. After about 50 welds, there were occasions when the tips appeared to be loading up, but just as this excess zinc appeared, the weld would flash and expel the zinc.

A second probable cause for the decrease in weld strength of the 1.25- and 1.70-oz. coated materials was electrode tip deformation.

Figures 4 and 5 show the set of tips used to make the series of 700 welds on the 1.25-oz. coated material. The tip in Fig. 4 was etched with concentrated hydrochloric acid. As can be seen in the photograph, the tip is pitted, definitely flattened and there appears to be a tendency for the tip material to flow. Figure 5 shows the tip in the unetched condition, and the zinc can be seen as a bright matrix.

It should be noted that the 2-in. radius dome tip gives theoretical point contact in the initial condition. Any tendency to flatten this tip will increase the contact area and consequently decrease the weld current density.

Fig. 4 Etched electrode tip

Electrode tips (2-in. radius dome) after 700 spot welds on 1.25-oz./sq. ft. galvanized steel. (Magnification 5 ×)

The modified tip with the 120° truncated cone was, of course, forced to maintain a constant contact area. The contact area, when etched, appeared quite similar to that shown in Fig. 4.

Appearance of the Weld

In use of 2-in. radius dome electrode tips, the appearance of the weld is greatly changed as the number of welds increases. Figures 6 and 7 are photographs of welds number 4 and 684, respectively, in the series

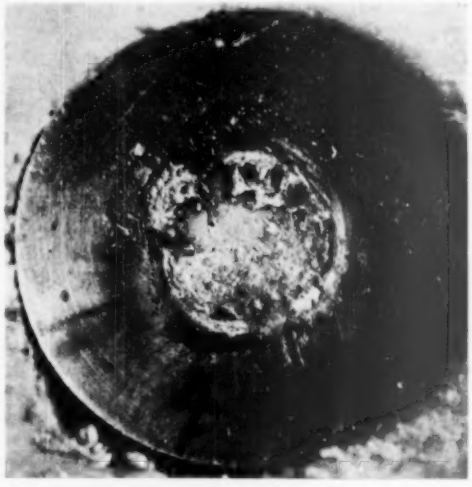

Fig. 5 Unetched electrode tip

Electrode tips (2-in radius dome) after 700 spot welds on 1.25-oz./sq. ft. galvanized steel. (Magnification 5 ×)

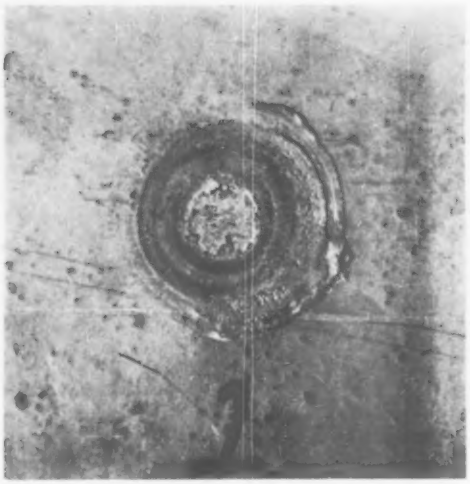

Fig. 6 Weld No. 4 in a series of 700 spot welds on 1.25-oz./-sq. ft. galvanized steel. (Magnification 5 ×)

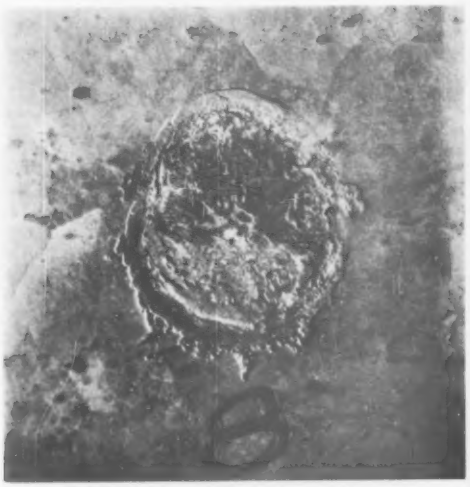

Fig. 7 Weld No. 684 in a series of 700 spot welds on 1.25-oz./-sq. ft. galvanized steel. (Magnification 5 ×)

made on the 1.25-oz. coated material. Weld number 4 is a good example of one which has good symmetry, reasonable penetration and is, in general, satisfactory.

The 694th weld has increased in area over the 4th weld by about 60%. It has also lost the appearance of being made by a dome-shaped tip. It is a good example of a weld with poor appearance.

The appearance of the welds made with the modified tip was excellent throughout the series; it compared favorably with that shown in Fig. 6.

It was found that mild flashing and sticking of the weld appeared in all cases after approximately 100 welds. Yet neither in any instant reached a sufficient consequence to be objectionable.

CONCLUSIONS

The following conclusions have been reached as a result of these investigations. They apply specifically to the materials welded in these tests under the conditions selected. The general trends can be applied to the welding of most galvanized sheet steel.

1. Electrode tip deformation is the primary cause for poor weld strength and appearance in a long series of spot welds on galvanized steel.

2. An increase in contact area causes a decrease in current density, with a consequent decrease in weld strength.

3. Zinc pickup on the electrode tips in itself does not have detrimental effects of consequence on the weld nugget, either from the standpoint of strength or appearance. In fact, it tends to prevent excessive expulsion of zinc from the welded material after about 50 welds.

4. Flashing and sticking of the weld components are primarily caused by too much energy in the welding process. There is no apparent correlation between the number of welds made and the amount of flashing and sticking.

5. A hard-tip material such as chromium copper should be used while welding galvanized steel to eliminate tip deformation.[8]

6. The shape of the tip should be such that the contact area does not tend to change as the number of welds increases.

7. The length of the stroke should be a minimum to lessen the impact which increases deformation. Any other method of lessening the impact, such as a lighter walking beam, should be employed.

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Even when the Skeleton of Theory is a bit shaky, it should be frankly and briefly presented, together with such hypotheses as have proved useful. As far as possible the data presented should be woven into the theory in an effort to make it a rational structure. The results of such an effort may constitute the most important part of the contribution.

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Wherever possible, data should be reduced to tabular form, charts or simple formulas. Full and complete information must be given in terms which the engineer readily understands and uses without employing unnecessary high-brow-sounding vocabulary. Wherever possible these data should be marshaled in such form as to indicate the soundness of the hypotheses or formulas. If specifications are involved they should include terminology and specification numbers commonly used, with type or grade numbers.

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The authors should anticipate difficulties which will be encountered by the average engineer. How to avoid these difficulties, if possible, should be indicated. How to minimize the trouble or alleviate the conditions should also be included.

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On all of these controversial subjects there are regions where the engineer can be sure of his ground. In other instances there is the realm of the unknown. Wherever possible these regions should be definitized. If possible itemized research projects should be indicated with relative priority of importance.

CONCLUSIONS

As a result of the survey of published data, theory and other evidence, it should be possible to arrive at certain useful conclusions which will indicate the practical limits within which the engineer can apply what is indicated as reasonably proved or which may be expected with reasonable probability, based upon present knowledge.

APPENDIXES

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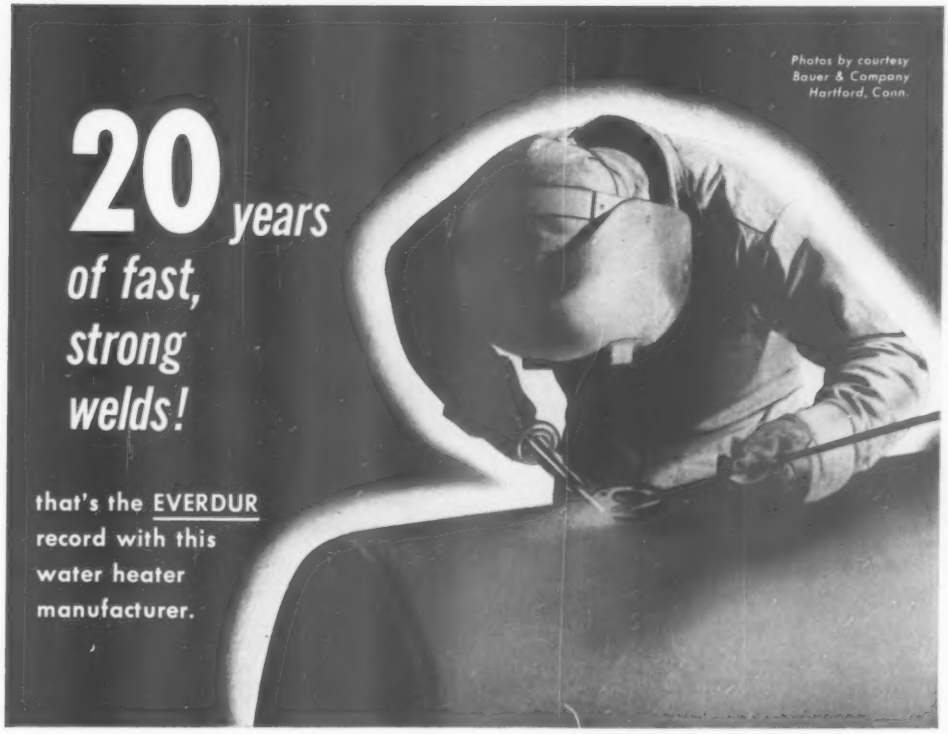

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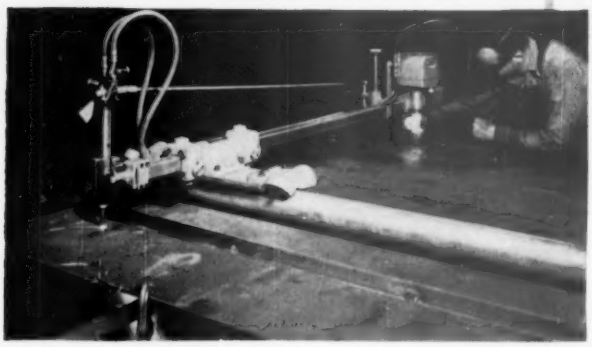

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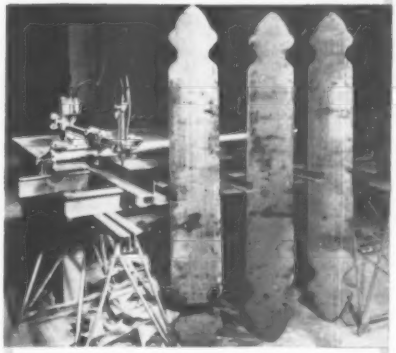

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